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RESEARCH MEMORANDUM

LOW-SPEED STATIC STABILITY CHARACTERISTICS OF A
CANARD MODEL WITH A 45° SWEPTBACK WING AND A
 60° TRIANGULAR HORIZONTAL CONTROL SURFACE

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LOW-SPEED STATIC STABILITY CHARACTERISTICS OF A
CANARD MODEL WITH A 45° SWEEPBACK WING AND A
 60° TRIANGULAR HORIZONTAL CONTROL SURFACE

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SUMMARY

An investigation has been made of the low-speed static stability characteristics of a canard model with a 45° sweptback wing and a 60° triangular horizontal control surface. The model had practically no allowable center-of-gravity range because of longitudinal instability that occurred at moderate and high lift coefficients with horizontal-control-surface incidences of 10° or less. The horizontal control surface produced a sidewash which, at an incidence of 15° and at angles of attack greater than 7° , was strong enough to make the model directionally stable with the vertical tail off. This sidewash caused a vertical tail mounted on the fuselage to be destabilizing at angles of attack above 11° . Twin vertical tails mounted at the wing tips did not produce a similar destabilizing effect because they were located outside the sidewash field.

INTRODUCTION

Interest in canard airplanes has recently been revived because the results of several studies have indicated that the canard appears promising for use at transonic and supersonic speeds (for example, reference 1). The National Advisory Committee for Aeronautics is making a general study of canard airplanes and results of several investigations are presented in references 1 to 5. As part of this general study, an investigation has been made in the Langley free-flight tunnel to determine the low-speed static stability and control characteristics of a canard model. The configuration tested was similar to that of references 1 to 3 and had a circular-cross-section fuselage with a fineness ratio of 13.5, an untapered 45° sweptback wing with aspect ratio 4.1, an untapered 45° sweptback vertical tail at the extreme rear of the fuselage, and a 60° triangular horizontal control surface at the nose.

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The present investigation consisted of force tests to determine the longitudinal and lateral stability characteristics of the complete model and of various combinations of the fuselage, wing, vertical tail, and horizontal control surface. Tests were also made to determine the effects on the lateral stability of several changes in the horizontal control surface and vertical-tail configurations.

SYMBOLS AND COEFFICIENTS

All forces and moments are measured about the stability axes which are defined in figure 1.

C_L	lift coefficient ($Lift/qS$)
C_D	drag coefficient ($Drag/qS$)
C_m	pitching-moment coefficient ($Pitching\ moment/qS\bar{c}$)
C_l	rolling-moment coefficient ($Rolling\ moment/qSb$)
C_Y	lateral-force coefficient ($Lateral\ force/qS$)
C_n	yawing-moment coefficient ($Yawing\ moment/qSb$)
q	dynamic pressure, pounds per square foot ($\frac{1}{2}\rho V^2$)
ρ	air density, slugs per cubic foot
V	airspeed, feet per second
S	wing area, square feet
b	wing span, feet
\bar{c}	mean aerodynamic chord of the wing, feet
α	angle of attack of fuselage center line, degrees
ψ	angle of yaw, degrees
β	angle of sideslip, degrees ($-\psi$)
$C_{n\beta}$	rate of change of yawing-moment coefficient with angle of sideslip in degrees ($\partial C_n / \partial \beta$)

$C_{l\beta}$	rate of change of rolling-moment coefficient with angle of sideslip in degrees ($\partial C_l / \partial \beta$)
$C_{Y\beta}$	rate of change of lateral-force coefficient with angle of sideslip in degrees ($\partial C_Y / \partial \beta$)
i_t	incidence of horizontal control surface (positive with leading edge up), degrees
b_t	span of horizontal control surface, feet
h_t	height of horizontal control surface above fuselage center line, feet
y_t	lateral location of center line of horizontal control surface (measured from fuselage center line), feet

Model designations:

F	fuselage
W	wing
V	vertical tail
H	horizontal control surface
(H)	horizontal control surface in position but not attached to model

Subscripts:

E	twin vertical tails located on wing tips
0,5,10	angle of incidence of horizontal control surface, degrees
R	rectangular-plan-form horizontal control surface

APPARATUS AND MODEL

The force tests to determine the static aerodynamic characteristics of the model were made on the six-component balance of the Langley free-flight tunnel described in reference 6.

A three-view drawing and a photograph of the model used in the investigation are given as figures 2 and 3, respectively. Dimensional

characteristics of the model are presented in table I. The model was constructed of hardwood and balsa with no movable surfaces other than the horizontal control surface. No appreciable gap was formed between the horizontal control surface and fuselage when the surface was deflected. The wing and the single vertical tail had an NACA 65-009 airfoil section normal to the leading edge (6.35 percent thick parallel to air stream) while the triangular horizontal control surface was a $\frac{1}{4}$ -inch-thick flat plate with a rounded leading edge and tapered trailing edge. The results obtained with the flat-plate airfoil section used on the model are approximately the same as would have been obtained with a conventional section because the aerodynamic characteristics of delta wings are virtually independent of the airfoil section at low scale. This characteristic has been established by comparison of the aerodynamic characteristics of some flat-plate delta wings from reference 7 with those of some German data on delta wings (reference 8) having NACA 0012 airfoil sections and with those of some unpublished data on a 60° delta wing with an NACA 0015-64 airfoil section. The twin vertical tails and rectangular horizontal control surface used in the investigation were flat plates. It was assumed that the results obtained with these flat-plate surfaces would be comparable to those obtained with conventional sections at low scale.

TESTS

Tests were made to determine the static longitudinal stability characteristics of the model over an angle-of-attack range. Lateral stability characteristics were determined over the angle-of-attack and angle-of-yaw ranges. Table II is an index which shows the combinations of the model components tested.

The lateral stability characteristics were determined in two ways. An indication of the variation of the lateral stability characteristics with angle of attack was obtained by determining the static lateral derivatives from the slope of the curves between the coefficients measured at angles of yaw of $\pm 5^\circ$. The lateral-stability coefficients were also determined from tests over a range of yaw angles from 20° to -20° for various angles of attack. For the case for which the variation of lateral coefficients with angle of yaw is nonlinear, the plots of lateral coefficients against angle of yaw give a better indication of the lateral stability of the model than the plots of the lateral-stability derivatives against angle of attack.

All tests were run at a dynamic pressure of 4.1 pounds per square foot, which corresponds to an airspeed of about 40 miles per hour at

standard sea-level conditions and to a Reynolds number of 3.2×10^5 based on the mean aerodynamic chord of the wing of 0.85 foot. All longitudinal data for the model are referred to a center-of-gravity position of 0.80 mean aerodynamic chord ahead of the leading edge of the mean aerodynamic chord of the wing unless otherwise noted. A center-of-gravity position of 0.56 mean aerodynamic chord ahead of the leading edge of the mean aerodynamic chord was used for all lateral data. The vertical position of the center of gravity was assumed to be the fuselage center line for all tests.

For some tests, streamers of string approximately 6 inches long were attached at various locations along the fuselage in order to permit observation of the direction of flow over the fuselage. These studies were made under the same conditions as the force tests.

RESULTS AND DISCUSSION

The results of force tests made to determine the static longitudinal and lateral stability characteristics of the model are presented in figures 4 to 24. Table II is an index to these figures and a key to the configurations tested.

Longitudinal Stability and Control

The results of the tests made with various incidence settings of the horizontal control surface are presented in figure 4. These results show that the model becomes unstable at a lift coefficient of about 0.9 with control-surface incidences of 0° , 5° , and 10° for a center-of-gravity position of 0.80 mean aerodynamic chord ahead of the mean aerodynamic chord; with horizontal-control-surface incidences of 15° and 20° , a stable pitching moment is obtained over the complete lift range because the horizontal control surface stalls at a lower angle of attack than the wing. The model also becomes unstable at a lift coefficient of about 0.9 with $i_t = 15^\circ$ when the center of gravity is moved rearward (fig. 5). The reason for the break in the pitching-moment curve is indicated by the curve for the horizontal control surface off in figure 4 and by figure 6 which presents the longitudinal characteristics of some of the component parts. The wing pitching-moment curve against angle of attack breaks upward, apparently because the wing lift-curve slope decreases and because the wing aerodynamic center is well behind the center of gravity. This point is illustrated more clearly by figure 7 in which the wing pitching-moment curve referred to the 0.25 mean aerodynamic chord is compared with the curve for 0.80 mean aerodynamic chord ahead of the mean-aerodynamic-chord position. When the data are presented about the wing quarter chord

the pitching-moment curve is approximately linear up to an angle of attack of 24° . Evidence that the falling off of the lift-curve slope is responsible for the break in the pitching-moment curve is given by the dashed lines of figure 7 which represent the case where the lift curve was assumed to be linear up to an angle of attack of 24° . If the wing lift holds up (which would be expected at higher Reynolds number) a linear pitching-moment curve is obtained. These results show that an early change in the slope of the lift curve of the wing is particularly undesirable for a canard airplane because the wing is well behind the center of gravity. For a conventional airplane this effect is much smaller (or perhaps, even in the opposite direction) because the center of gravity is much farther back.

The variation with angle of attack of the incremental pitching moment produced by the horizontal control surface at various incidences is shown in figure 8. The angle of attack at which the slope of the horizontal-control-surface-effectiveness curve begins to decrease is, of course, dependent on the angle of incidence of the surface. The horizontal-control-surface effectiveness remains essentially constant up to an angle of attack of about 30° for incidences of 0° and 5° . At tail incidences of 10° , 15° , and 20° the slope of the horizontal-control-surface-effectiveness curve decreases at lower angles of attack because of the decreasing lift-curve slope of the surface. This decrease in lift-curve slope decreases the pitching moment of the horizontal surface and tends to balance out the effect of the decrease in pitching moment caused by the decrease in lift-curve slope of the wing (figs. 4 and 5). If the lift-curve slopes of the wing and horizontal surface break at the same time (and by the proper amount) the pitching-moment curve for the complete model will tend to remain linear. For this model the isolated horizontal control surface starts to stall at about 28° angle of attack (reference 7) and the wing stalls at about 12° which is a difference of 16° between the stall angles. Therefore, with the incidence of 15° , the two effects should tend to balance out and give a more linear pitching-moment curve than those obtained with the lower angle of incidence. The data of figures 4 and 5 show that this is the case.

The allowable center-of-gravity range can be defined as the distance from the most rearward center-of-gravity location for which the model is at least neutrally stable in the trimmed condition to the most forward center-of-gravity location at which the model can trim to the maximum lift coefficient with horizontal control surface ($C_L = 1.1$). On this basis the model had practically no allowable center-of-gravity range because of the longitudinal instability that occurred at moderate and high lift coefficients with incidences of 10° or less (fig. 5). Canard designs which have a stable wing pitching moment and a horizontal control surface which stalls at the same time as the wing would probably have a somewhat greater center-of-gravity range.

Lateral Stability and Control

The results of lateral-stability force tests of the complete model are presented in figures 9 and 10. The data of figure 9 are presented in the form of lateral-stability derivatives which were obtained by measuring the forces and moments at $\pm 5^\circ$ yaw and by assuming a linear variation of the lateral coefficients between $\pm 5^\circ$. The data of figure 10 show the variation of the lateral coefficients with angle of yaw and indicate that the variation between $\pm 5^\circ$ yaw is not linear for all conditions. Therefore, the results obtained from the tests of angle of yaw of $\pm 5^\circ$ should be used only as qualitative data. Absolute values of the lateral-stability derivatives should be measured from the curves of lateral coefficients plotted against angle of yaw.

The results of figures 9 and 10 show that, for a horizontal-control-surface incidence of 0° , the directional stability derivative $C_{n\beta}$ decreased with increasing angle of attack. These results also show that an increase in tail incidence caused an increase in $C_{n\beta}$ as well as in the effective dihedral derivative $-C_{l\beta}$ and resulted in a change in sign of the lateral-force derivative $-C_{Y\beta}$ at moderate and high angles of attack.

The variation of the lateral-stability derivatives with angle of attack for a center-of-gravity position within the allowable center-of-gravity range (0.70 M.A.C. ahead of the leading edge of the mean aerodynamic chord) and with the horizontal control surface set at the proper position for trim is shown in figure 11. These results show that the model is directionally stable over the angle-of-attack range under these conditions.

Presented in figures 12 to 16 are the results of tests made of various components individually and in combinations in an effort to explain these effects of horizontal-control-surface incidence on the lateral stability. The results of figures 12 and 14(a) show that the lateral characteristics of configuration FWV are normal for such an arrangement. With the addition of the horizontal control surface at 0° incidence, however, (configuration FWH₀) there is a rapid reduction in $C_{n\beta}$ and $-C_{Y\beta}$ with increasing angle of attack in the moderate to high angle-of-attack range and an increase in $-C_{l\beta}$ at the moderate angles. On the other hand, tests made with the vertical tail off (FWH₀ and FWH₁₅ on figs. 13 and 14(b)) show that the horizontal control surface with 0° incidence had a small stabilizing effect (increased $C_{n\beta}$) at higher angles of attack, and with 15° incidence had such a large stabilizing effect that it resulted in the model with vertical tail off being directionally stable above an angle of attack of 7° . Tests made of the

combination of fuselage and horizontal control surface (FH_0 and FH_{15} on fig. 15) showed a similar effect of the tail to that shown by the data of figures 13 and 14 for the configurations (FWH_0 and FWH_{15}). The results of tests made to determine the variation of $C_{n\beta}$ at the higher angles of attack for configurations FWH_{15} and $FWVH_{15}$ are presented in figure 16. These results show a rapid increase in $C_{n\beta}$ for both configurations at the higher angles of attack. The results of figures 12 to 16 indicate that the horizontal control surface with $i_t = 15^\circ$ causes the vertical tail to be directionally destabilizing above an angle of attack of 11° and causes the fuselage to be directionally stable at moderate and high angles of attack.

A more definite indication of the effect of the horizontal control surface on the lateral stability is given in figure 17 where results of tests of the configurations FW, H_{15} , FWH_{15} , and $FW(H_{15})$ are presented. The data for the H_{15} configuration were obtained by testing the isolated horizontal control surface on a sting mounting and referring the forces and moments to the center-of-gravity position for the complete model. The $FW(H_{15})$ results were obtained with the surface in position with respect to the fuselage but without the surface being supported by the fuselage. These results show that the horizontal control surface alone and the wing-fuselage combination are unstable. When the horizontal control surface and wing fuselage are combined, however, the resulting configuration is stable above 7° angle of attack. With the horizontal control surface in its normal position but not attached to the model, approximately the same stabilizing effect is obtained as that with the control surface attached when tested at 20° angle of attack. The results of these tests indicate that the stabilizing effect of the horizontal control surface is not caused by the forces on the surface but is caused by the influence of the surface on the flow field about the model.

The results of tuft surveys made to obtain a physical picture of the flow field about the model at small angles of yaw are illustrated schematically in figure 18. These studies showed that at 0° angle of attack the streamers trailed essentially parallel to the air stream when the model was yawed. At 16° angle of attack, however, the streamers did not trail parallel to the air stream when the model was yawed but trailed across the fuselage in the opposite direction indicating that there was an effective reversal in the angle of sideslip of the model caused by a sidewash from the horizontal control surface. This change in the direction of flow over the fuselage came about gradually as the angle of attack was increased.

Effect of vertical position of horizontal control surface.— Presented in figures 19 and 20 are the results of a series of tests made

with the horizontal control surface at several different vertical positions in an effort to determine the vertical location of the sidewash field. Figure 19 shows that at 0° angle of attack the horizontal control surface ($i_t = 15^\circ$) was destabilizing (decreased C_{np}) when it was located on the fuselage center line but was stabilizing when it was located 0.25 control-surface span above the center line. At 20° angle of attack, the surface was stabilizing in both positions with the greatest effect occurring with the surface on the center line. When the surface was located 0.50 horizontal-control-surface span above the fuselage center line the effect of the surface was relatively small at all angles of attack; this small effect indicates that the sidewash was missing the fuselage. Figure 20 is a summary of the effect of the surface with $i_t = 15^\circ$ at 0° angle of attack which shows that the greatest effect occurs when the surface is located about 0.125 span above the center line. These results indicate that the sidewash field has a slight downward inclination. As the angle of attack is increased, more of the fuselage becomes immersed in the sidewash field and a greater stabilizing effect is obtained.

Effect of plan form of horizontal control surface.- In order to determine whether the unusual sidewash characteristics were associated only with a horizontal control surface with a triangular plan form, tests using a surface of rectangular plan form with the same area and aspect ratio as the triangular surface were made. These results are compared with those for the triangular surface in figure 21 which shows that the same effect exists to a limited extent for the rectangular surface. The smaller effect of the rectangular surface is apparently caused partly by the lower angle of attack at which it stalls. With 15° incidence the break in the variation of C_{np} with angle of attack occurs at 16° angle of attack for the model with the triangular surface and at 8° angle of attack for the model with the rectangular surface. If interference effects are neglected, these results might be taken to indicate that the triangular surface stalls at about 31° angle of attack and the rectangular surface stalls at about 23° angle of attack. These stalling angles are in fairly good agreement with those shown in reference 7 for wings of similar plan form.

Effect of vertical-tail configuration.- The results of tests made to determine whether twin vertical tails located at the wing tips would be free of the influence of the horizontal control surface are presented in figures 22 to 24. The data of figure 22 show that the twin vertical tails provide approximately a constant increment of C_{np} over most of the angle-of-attack range. Figures 23 and 24 show that the twin tails give a linear variation of yawing moment with angle of yaw of about 15° ; this linear variation indicates that the tails are not influenced by the sidewash field up to that angle of yaw.

Effect of horizontal control surface as a lateral-control device.-

When it was found that the sidewash created by the horizontal control surface had a large effect on the lateral characteristics, tests were made to determine whether this effect could be used to provide lateral control. The results of these tests in which the horizontal control surface was moved to several different lateral positions are presented in figure 25. These results show that large yawing and rolling moments were obtained at 15° angle of attack and 15° surface incidence. Moving the surface to the left apparently caused a sidewash to the right which gave positive values of lateral force and yawing moment. Large values of rolling moment were produced because the horizontal-control-surface lift was laterally displaced and because the wing was partly immersed in the sidewash field. These results indicate that, in some flight conditions, turning maneuvers might be executed by the lateral displacement of the horizontal control surface.

CONCLUSIONS

The following conclusions were drawn from the results of the Langley free-flight-tunnel investigation of the low-speed static stability characteristics of a canard model having a 45° sweptback wing and vertical tail and a 60° triangular-plan-form horizontal control surface.

1. The model had practically no allowable center-of-gravity range because of longitudinal instability that occurred at moderate and high lift coefficients with a horizontal-control-surface incidence of 10° or less. This longitudinal instability was caused by a premature dropping off of the wing lift-curve slope which was attributed, at least partly, to the low scale of the tests.

2. The horizontal control surface produced a sidewash which made the fuselage less directionally unstable and the vertical tail less directionally stable as the angle of attack and angle of the horizontal control surface were increased. At a horizontal-control-surface incidence of 15° , the sidewash effect was strong enough to make the model directionally stable with the vertical tail off at angles of attack greater than 7° and to cause a vertical tail mounted on the fuselage to be destabilizing at angles of attack above 11° . The results indicated that, for a center-of-gravity position within the allowable center-of-gravity range, the model would be directionally stable over the entire lift range if the horizontal control surface was set at the proper

position for trim. Twin vertical tails mounted at the wing tips did not produce a destabilizing effect because they were located outside the sidewash field.

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TABLE I
 DIMENSIONAL CHARACTERISTICS OF THE CANARD MODEL
 OF THE LANGLEY FREE-FLIGHT TUNNEL

Wing (W):

Airfoil section	NACA 65009
Chord (normal to L.E), in.	7.20
Span, in.	42.00
Area, (including area covered by fuselage) sq ft	2.95
Mean aerodynamic chord, in.	10.20
Aspect ratio	4.1
Sweepback (O.50c), deg	45.0
Taper ratio	1.0
Incidence, deg	0
Dihedral, deg	0
Twist, deg	0

Horizontal control surface (triangular) (H):

Airfoil section	Flat plate
Root chord, in.	12.0
Span, in.	12.0
Area, (including area covered by fuselage) sq ft	0.50
Mean aerodynamic chord, in.	6.0
Aspect ratio	2.0
Sweepback, (L.E.)	60.0
Dihedral, deg	0
Tail length (from L.E. M.A.C. wing to L.E. M.A.C. of tail), in.	47.25

Horizontal control surface (rectangular) (HR):

Airfoil section	Flat plate
Root chord, tip chord, in.	6.0
Span, in.	12.0
Area, (including area covered by fuselage) sq ft	0.50
Mean aerodynamic chord, in.	6.0
Aspect ratio	2.0
Sweepback (L.E.)	0
Dihedral, deg	0
Tail length, (from L.E. M.A.C. wing to L.E. M.A.C. of tail), in.	46.65



TABLE I

DIMENSIONAL CHARACTERISTICS OF THE CANARD MODEL
OF THE LANGLEY FREE-FLIGHT TUNNEL - Concluded

Vertical tail (V):

Airfoil section	NACA 65009
Chord (normal to L.E.), in.	5.05
Span, in.	10.70
Area, (to fuselage center line), sq ft	0.53
Aspect ratio	1.5
Sweepback (0.50c), deg	45.0
Taper ratio	1.0
Tail length (from L.E. M.A.C. wing to L.E. M.A.C. of tail), in.	20.57

Twin vertical tails (V_E):

Airfoil section	Flat plate
Chord (normal to L.E.), in.	6.20
Span, in.	9.25
Area, (total), sq ft794
Aspect ratio	1.5
Sweepback (0.50c), deg	45.0
Taper ratio	1.0
Tail length (from L.E. M.A.C. wing to L.E. M.A.C. of tail), in.	12.02



TABLE II
INDEX TO TESTS

Type of test	Configuration ¹	Figure
Longitudinal	F	6
	W	6 and 7
	FW	6
	FWV	4
	FWVH ₀	4, 5, and 6
	FWVH ₅	4 and 5
	FWVH ₁₀	4 and 5
	FWVH ₁₅	4 and 5
	FWVH ₂₀	4
Lateral	F	11, 12, and 14
	H ₁₅	16
	W	11
	FW	11, 12, 14, 16, and 18
	FV	14
	FH ₀	14
	FH ₁₅	14
	FWV	11, 12, and 13(a)
	FWH ₀	12
	FWH ₁₅	12, 13(b), 15, 16, 18, 19, 20, 21, and 24
	FWH _{R15}	20
	FW(H ₁₅)	16
	FWVH ₀	9, 10(a), and 11
	FWVH ₁₀	9
	FWVH ₁₅	9, 10(b), 15, 21, and 22
	FWVEH ₁₅	21 and 22
Tuft tests	FWVH ₁₅	17

¹The configurations are denoted by: F, fuselage; W, wing; V, vertical tail; H, horizontal control surface; subscript numbers indicate control-surface incidence measured in degrees. Subscript R indicates rectangular tail. Subscript E indicates twin tails. Parentheses around (H₁₅) indicate horizontal control surface in position but not attached to fuselage.

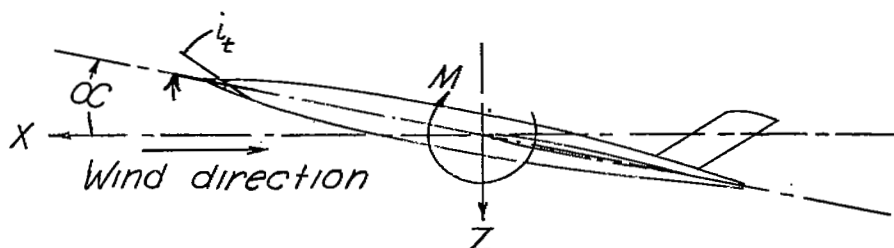
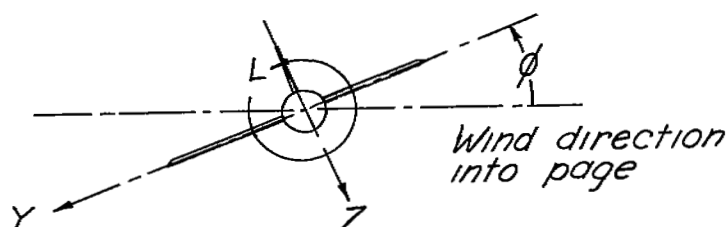
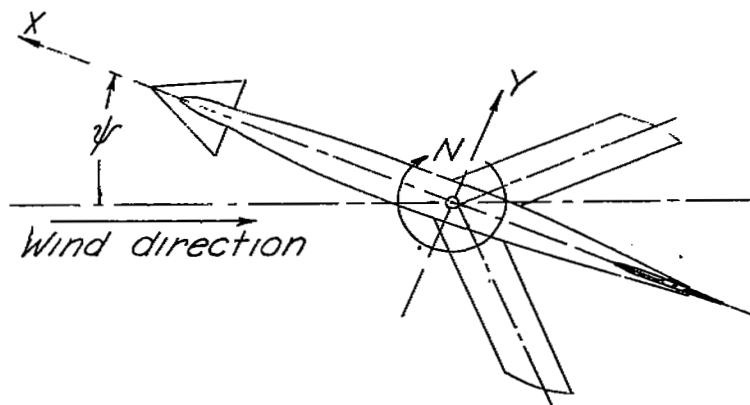


Figure 1.- The stability system of axes. Arrows indicate positive directions of moments, forces, and control-surface deflections. This system of axes is defined as an orthogonal system having their origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

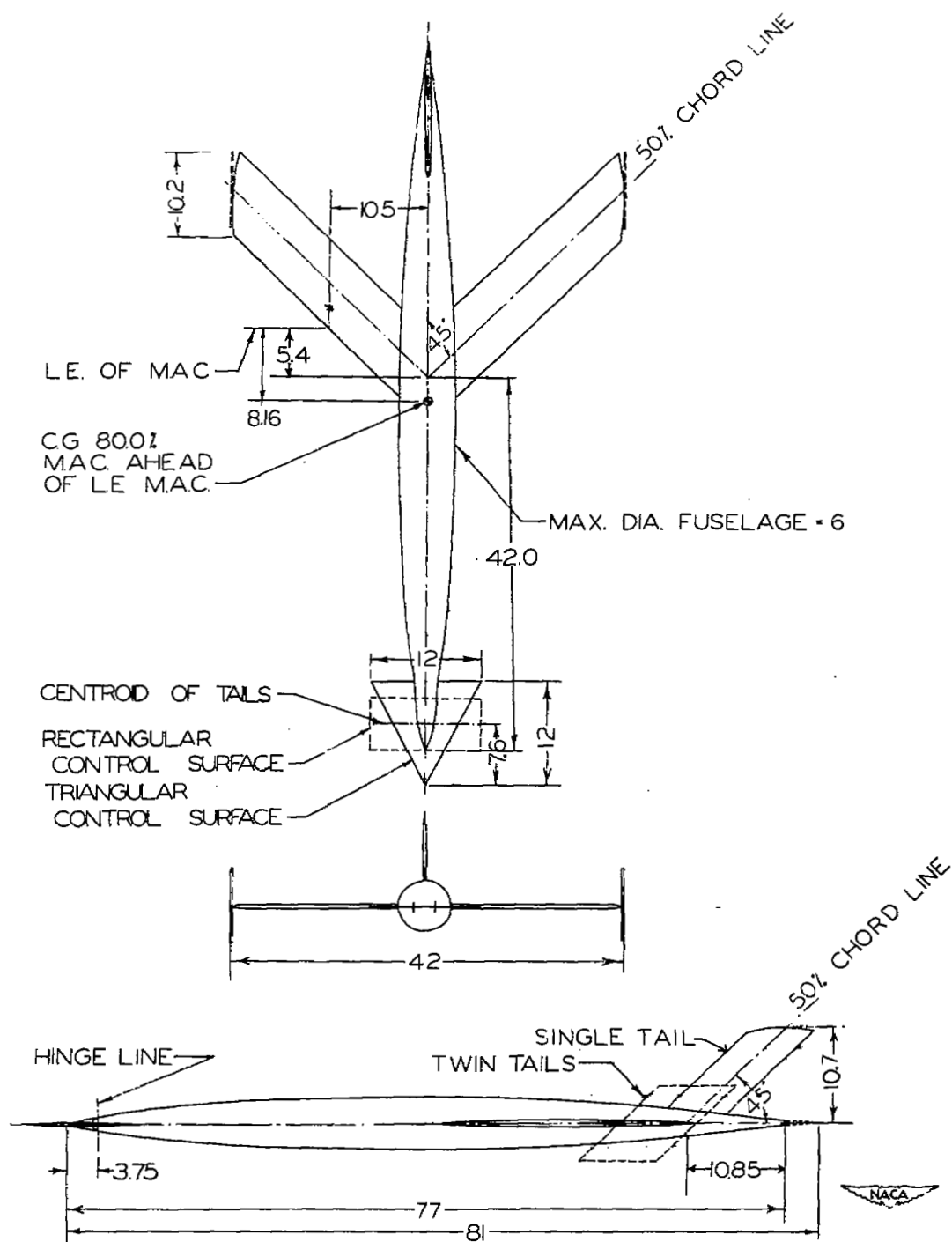


Figure 2.- Three-view drawing of model showing the various horizontal control surfaces and vertical-tail configurations. All dimensions are in inches.

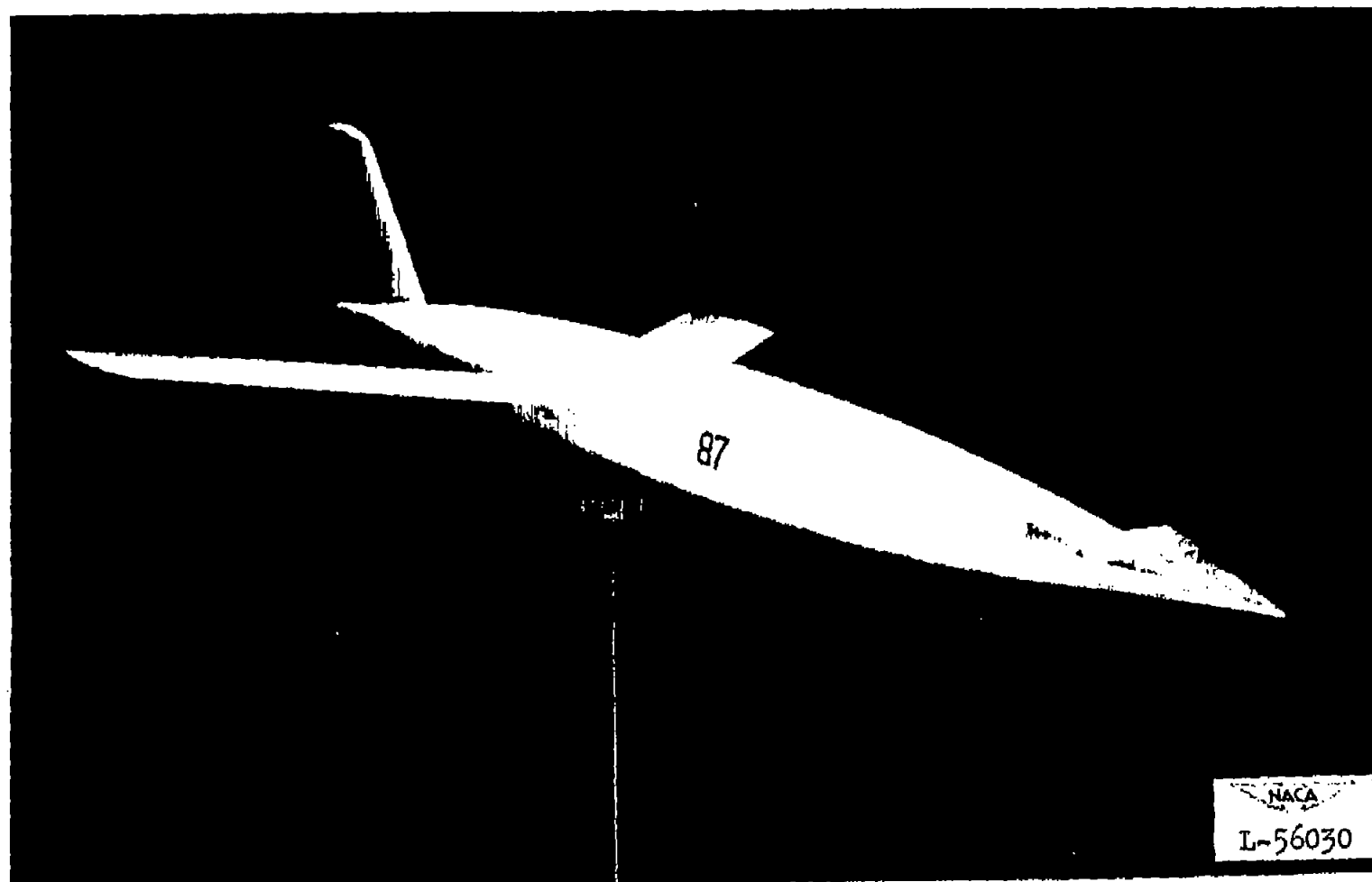


Figure 3.- Langley free-flight-tunnel canard model used in the investigation.

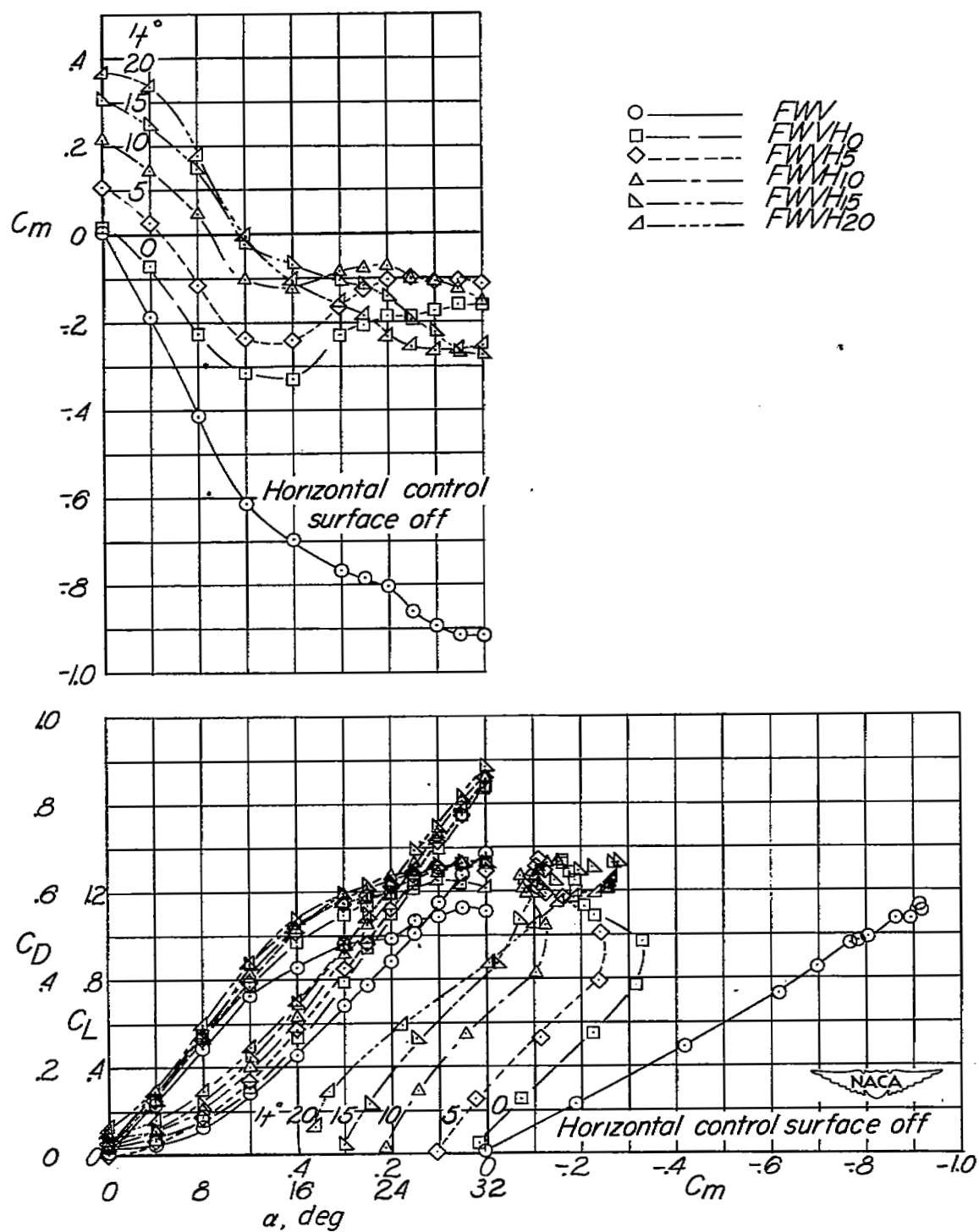


Figure 4.- Longitudinal stability characteristics of the model.

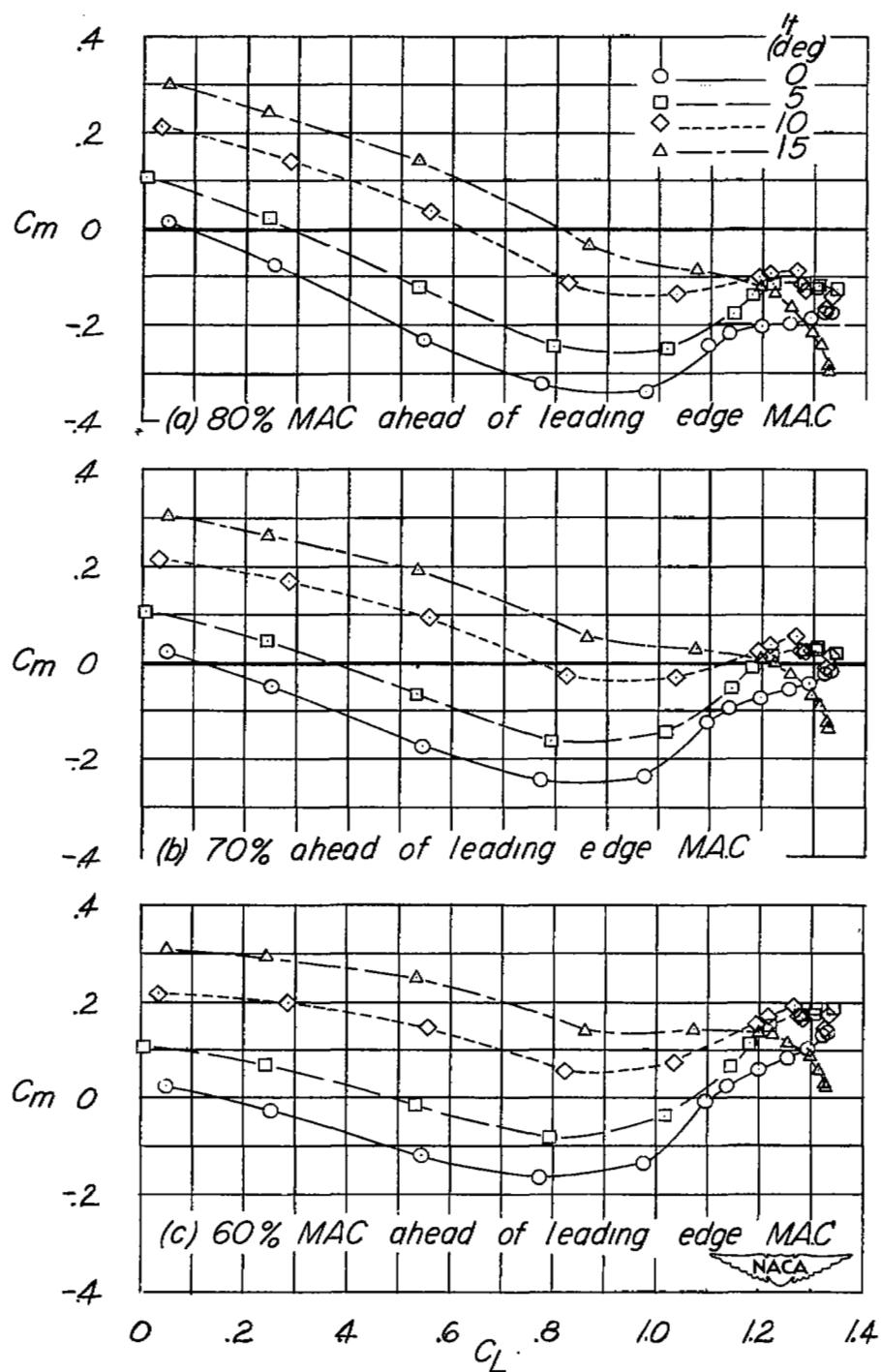


Figure 5.- The effect of horizontal-control-surface incidence and center-of-gravity location on the longitudinal stability and trim characteristics of the model.

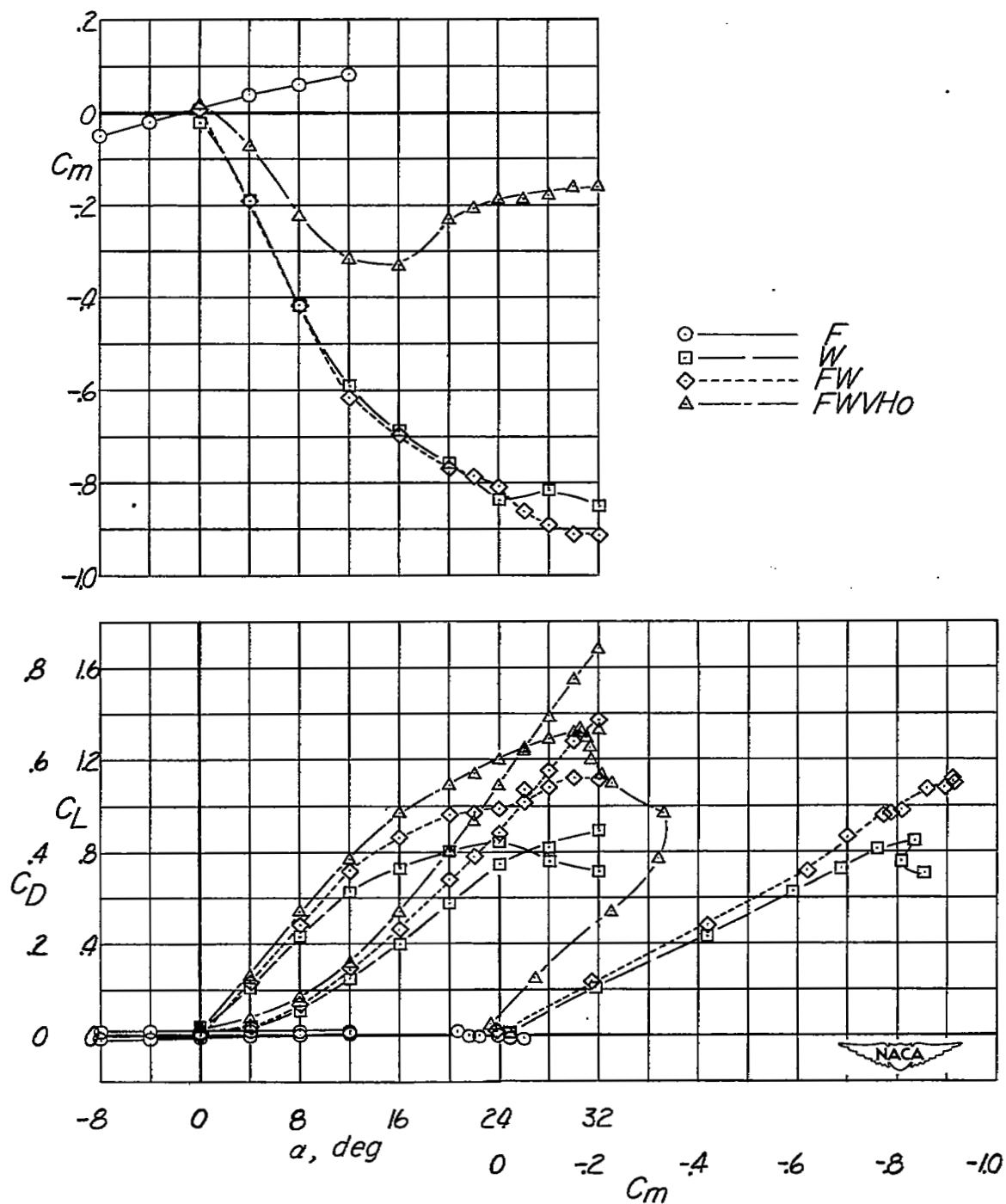


Figure 6.- Longitudinal stability characteristics of components of the model.

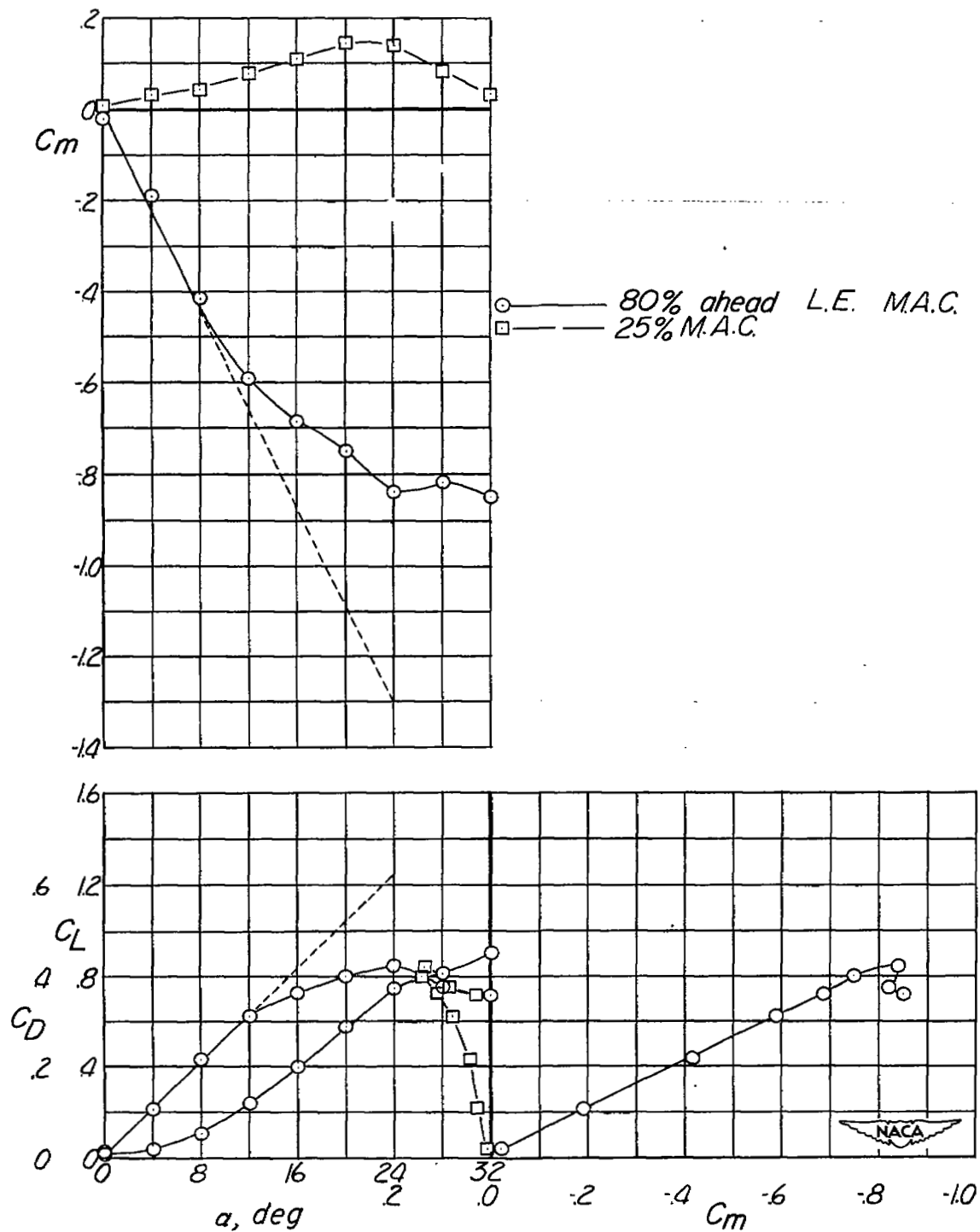


Figure 7.- Comparison of longitudinal stability characteristics of wing alone at two center-of-gravity locations.

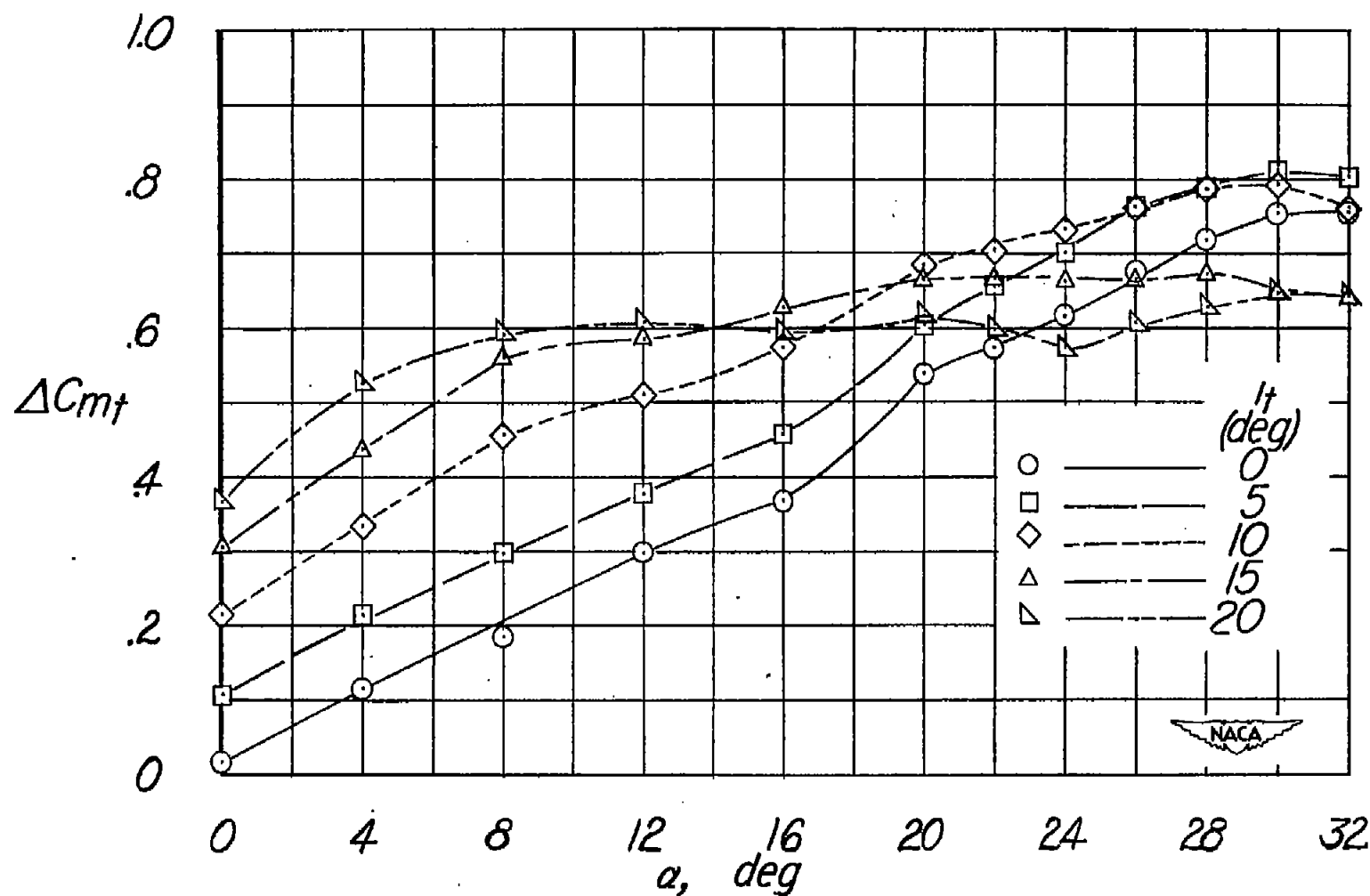


Figure 8.- Pitching effectiveness of triangular horizontal control surface for the various horizontal-control-surface settings used in the tests of the model.

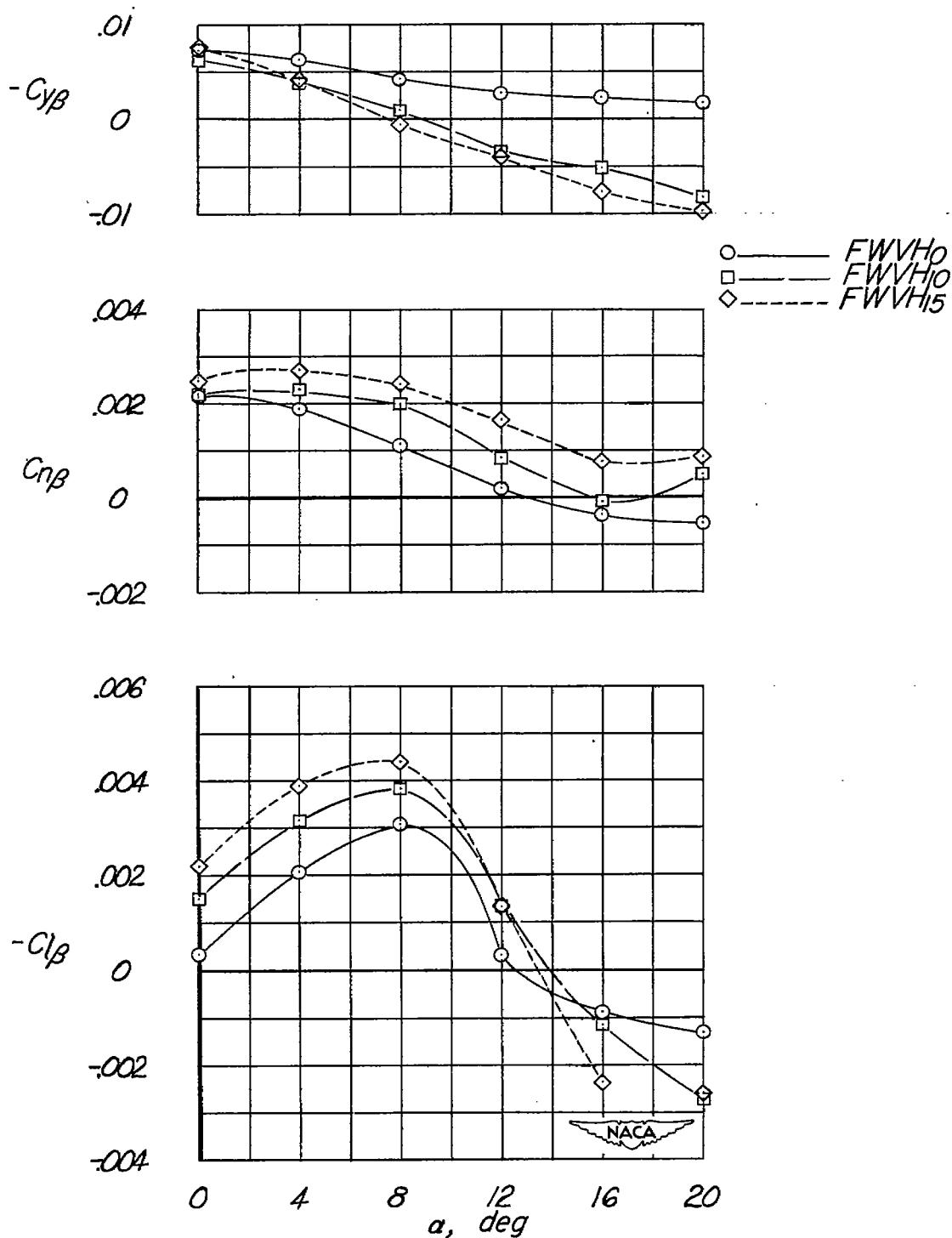
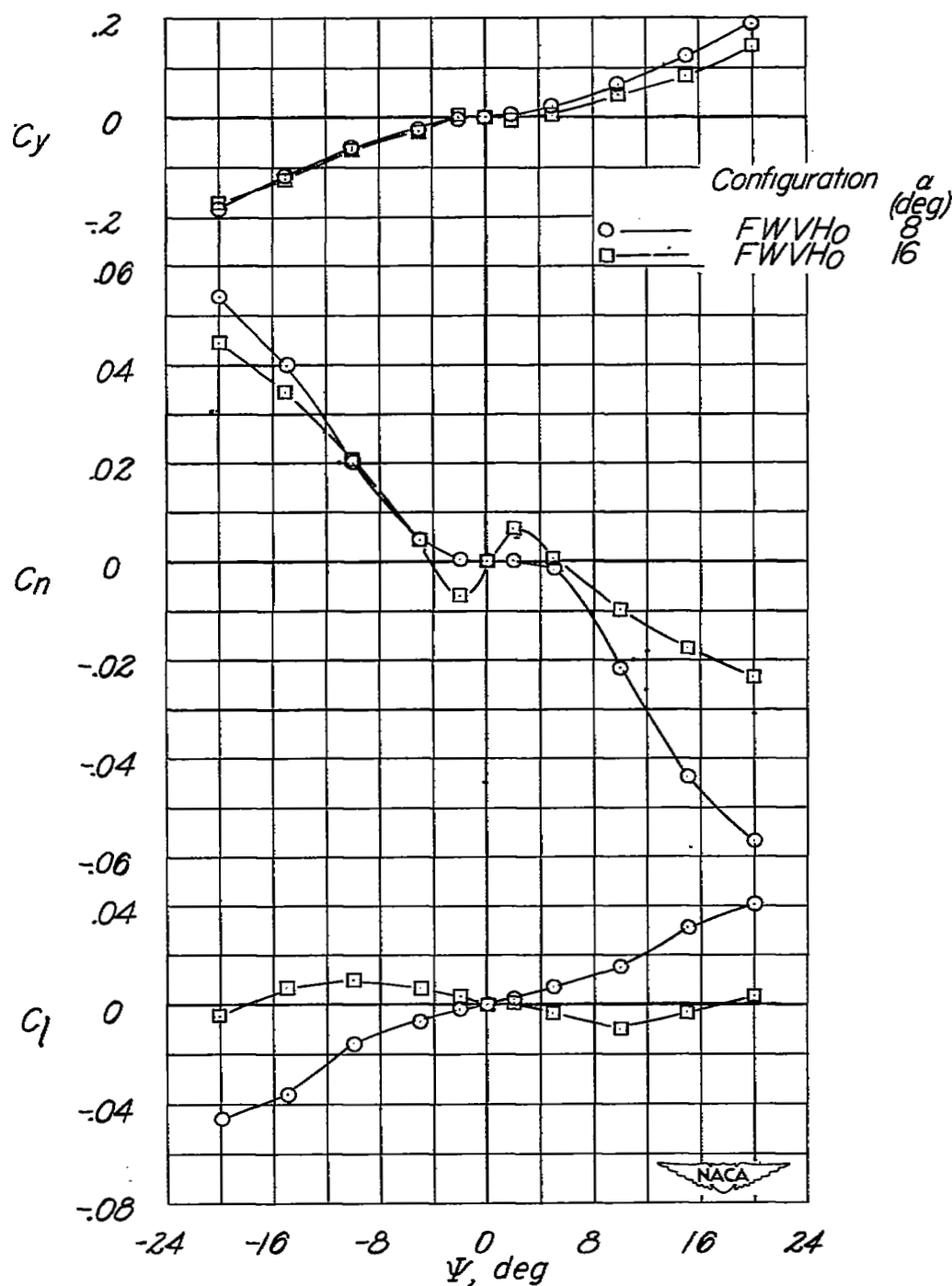
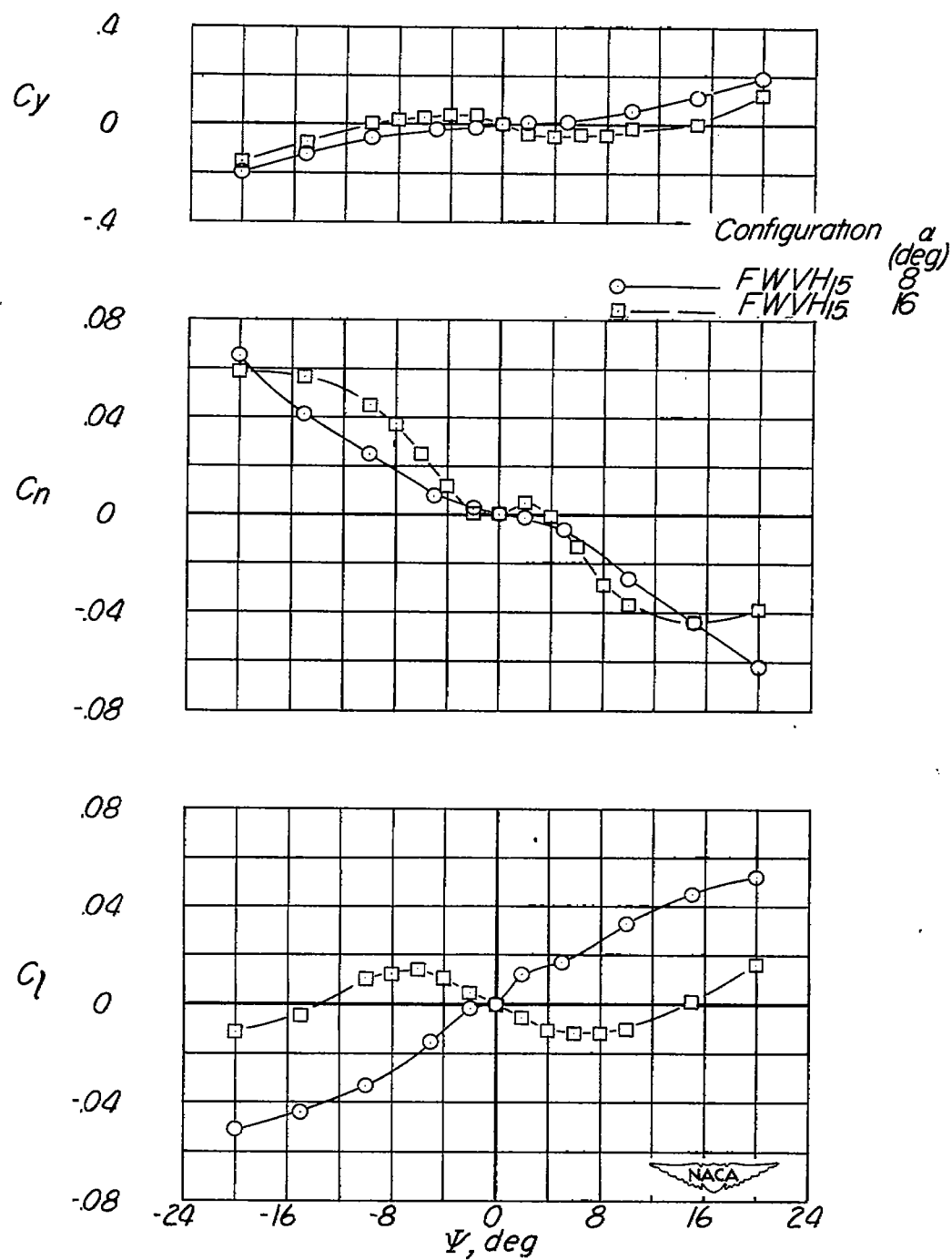


Figure 9.- Lateral stability characteristics of the model with various incidence settings of the horizontal control surface.



(a) Complete model configuration. $i_t = 0^\circ$.

Figure 10.- Lateral characteristics of the model.



(b) Complete model configuration. $i_t = 15^\circ$.

Figure 10.- Concluded.

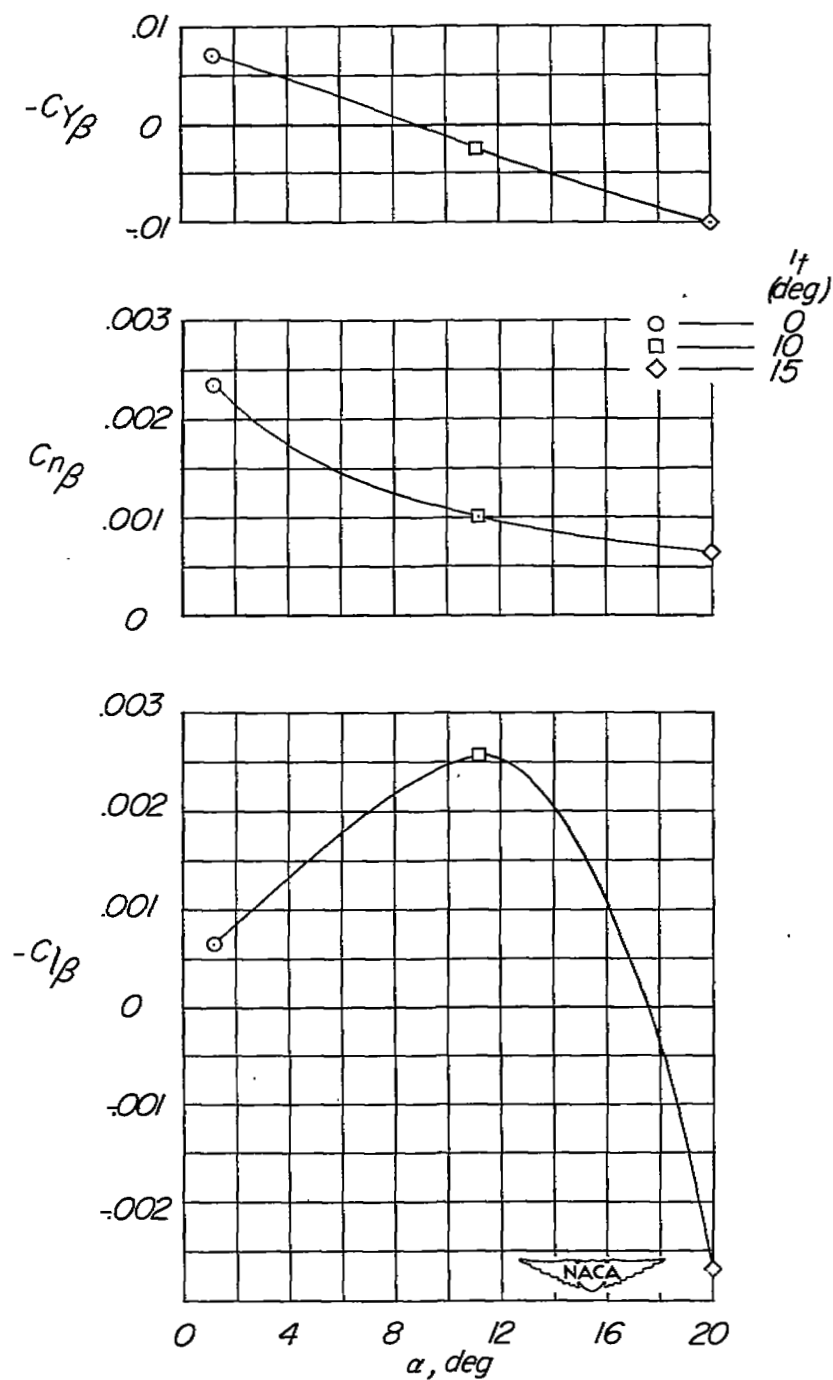


Figure 11.- Variation of lateral-stability derivatives with angle of attack for trim conditions of configuration FWVH with the center of gravity 0.70 mean aerodynamic chord ahead of the leading edge of the mean aerodynamic chord.

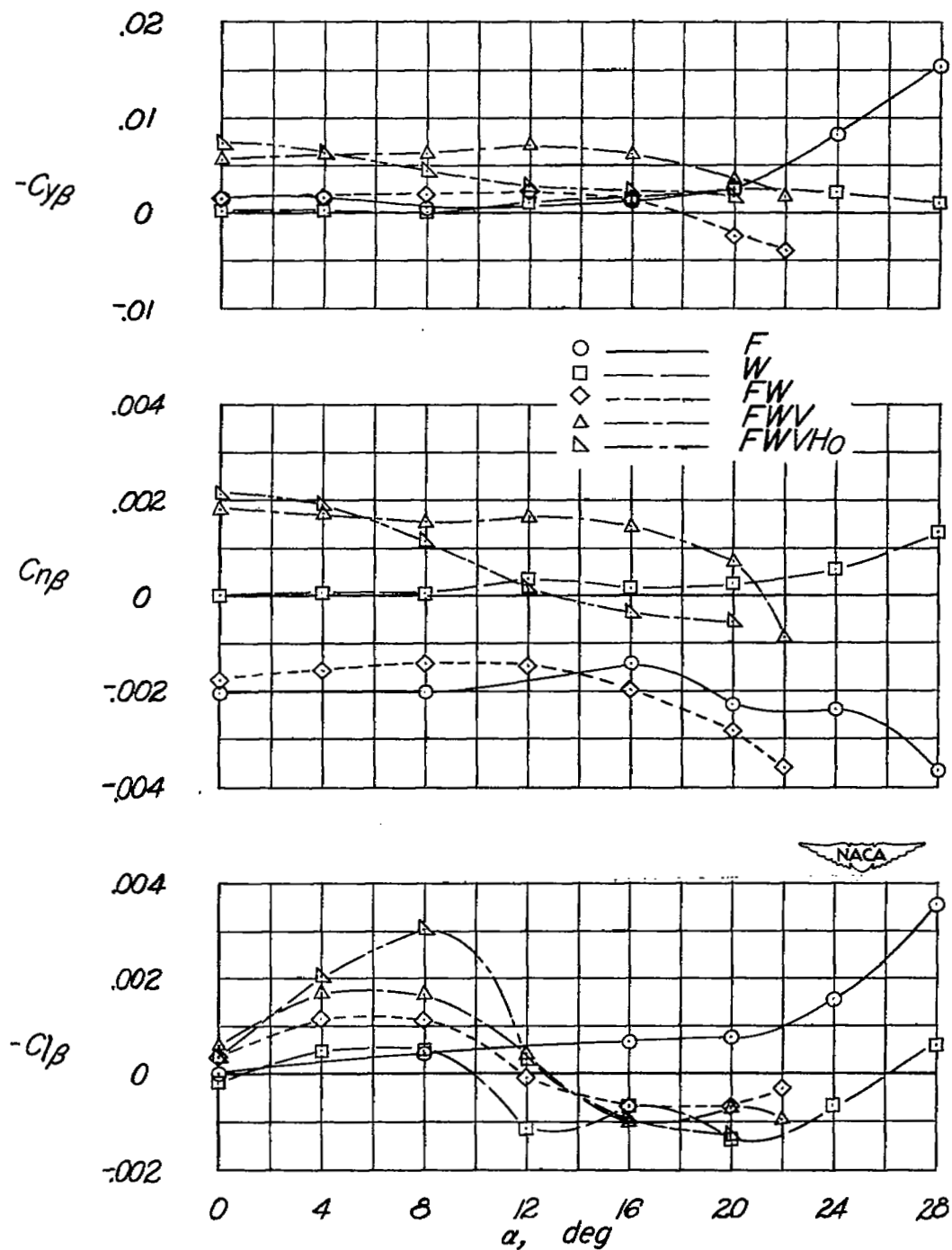
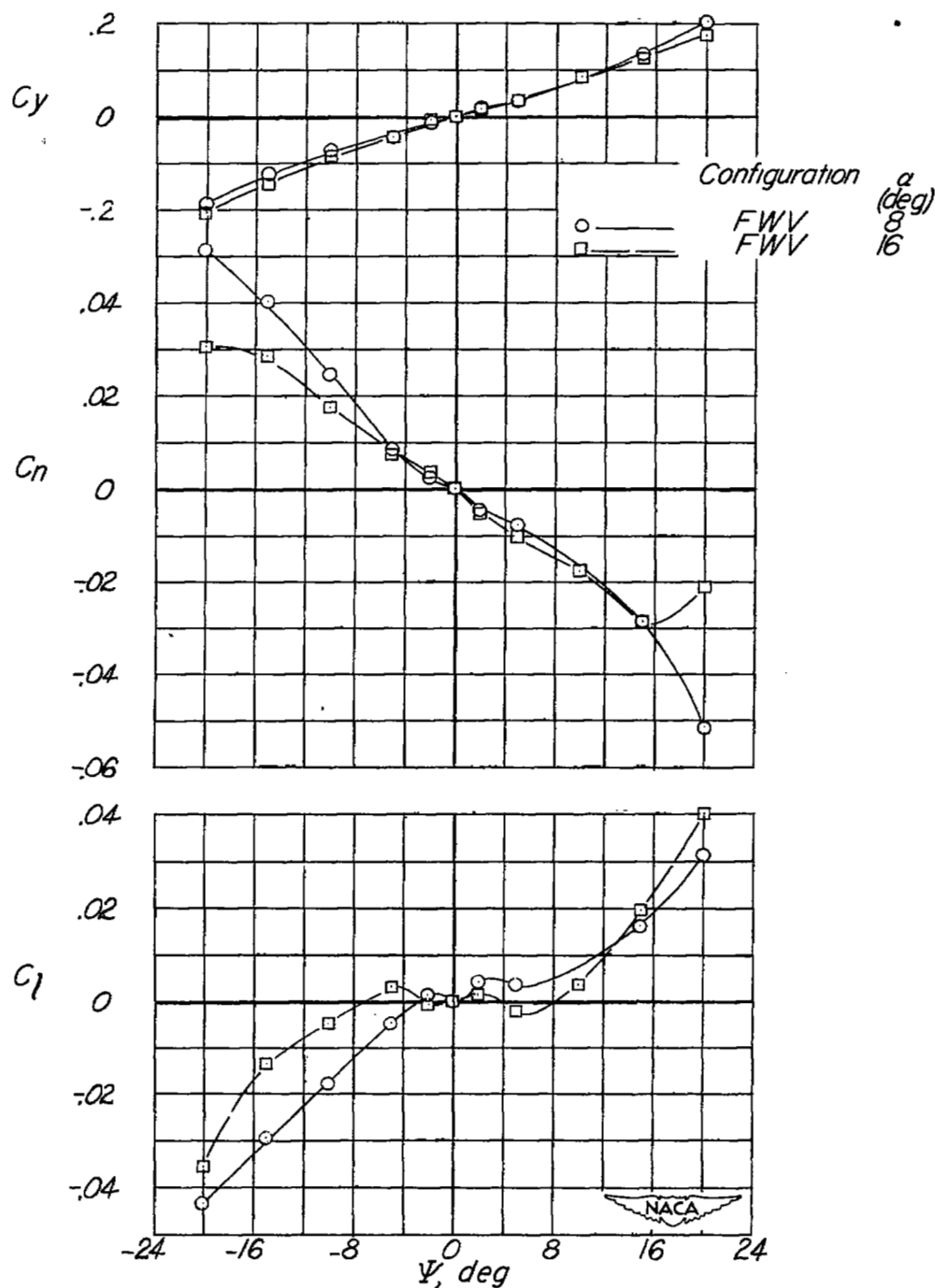
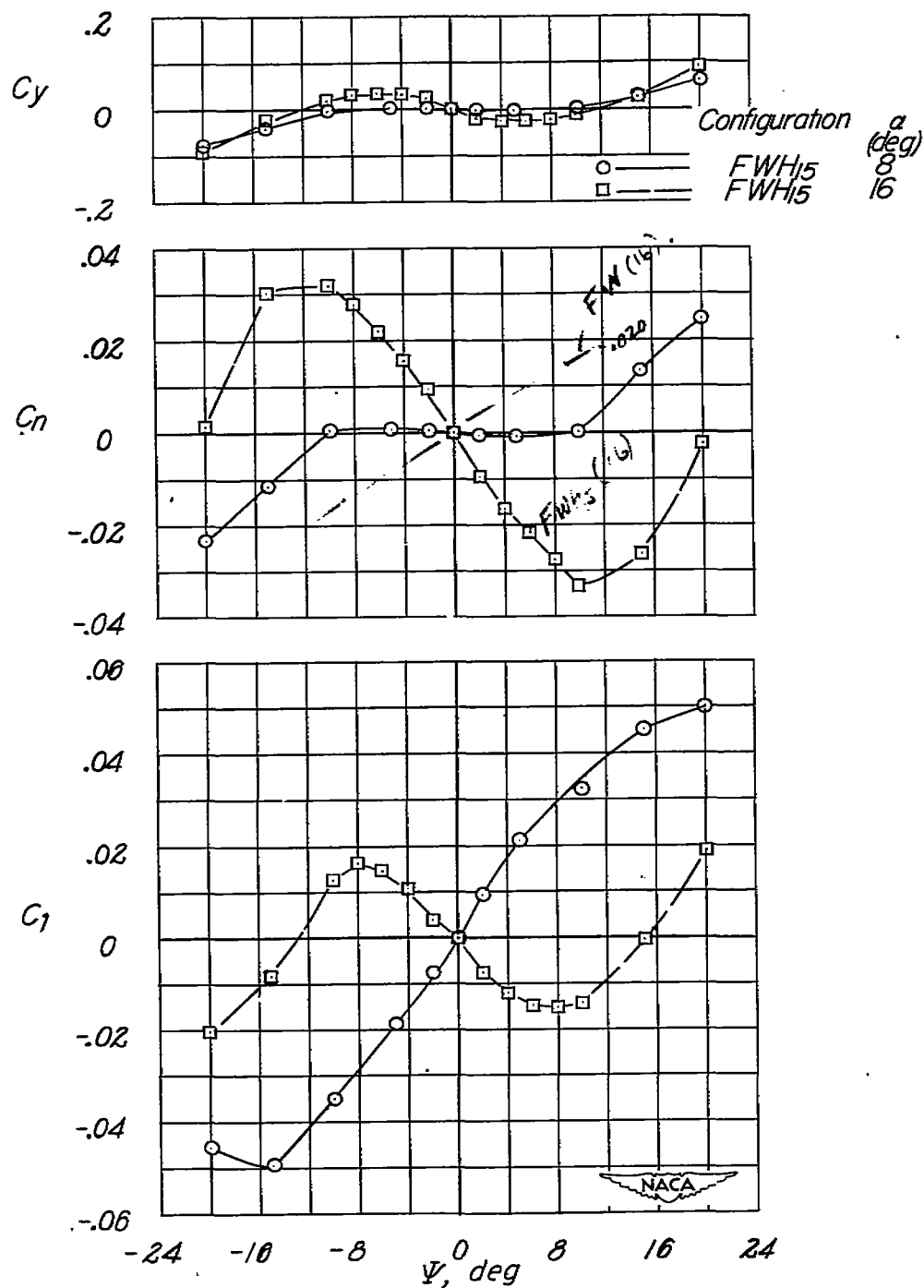


Figure 12.- Lateral stability characteristics of components of the model.



(a) Configuration of fuselage, wing, and vertical tail.

Figure 14.- Lateral characteristics of the model.



(b) Configuration of fuselage, wing, and horizontal control surface.

Figure 14.- Concluded.

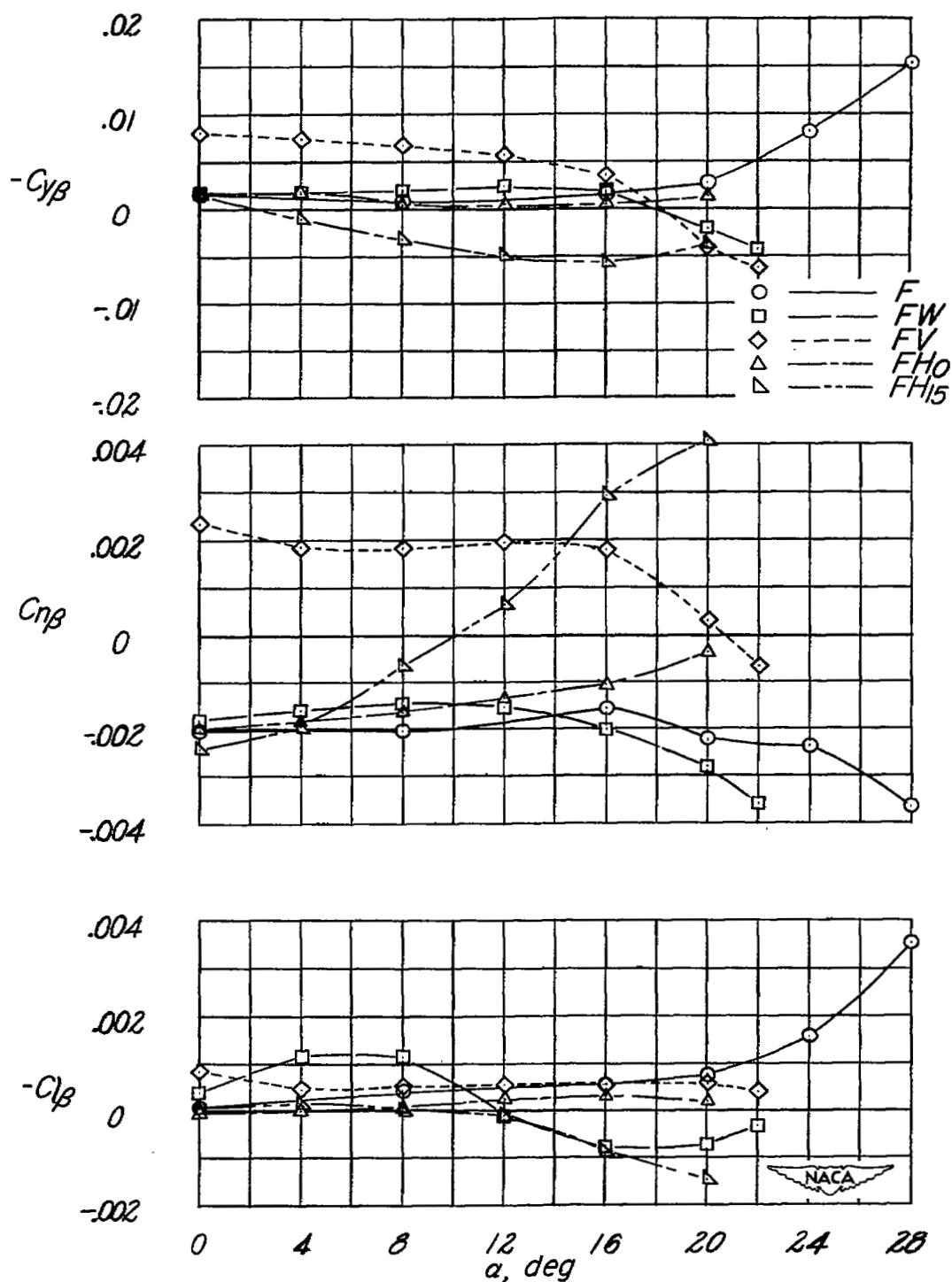


Figure 15.- Lateral stability characteristics of various components in combination with the fuselage.

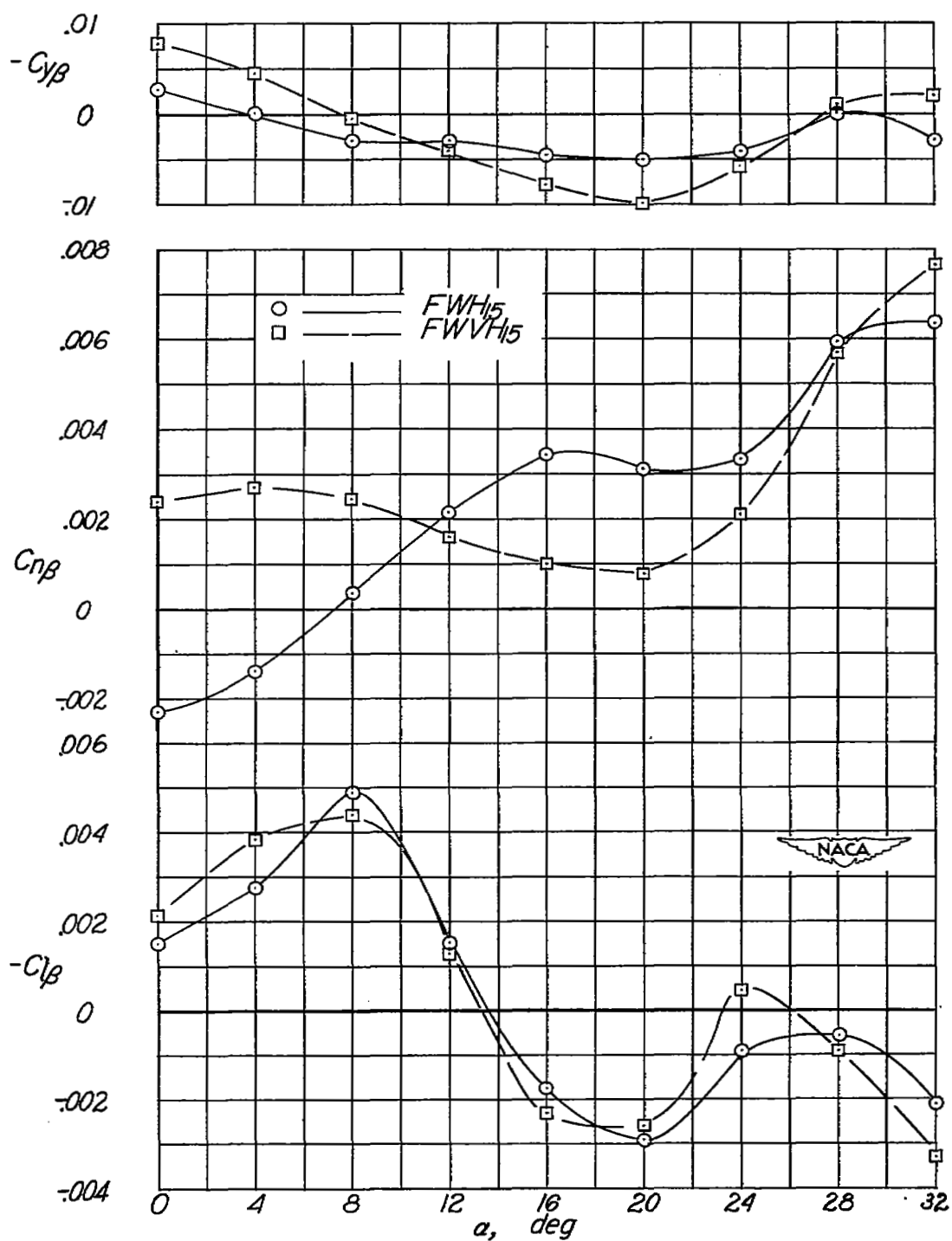


Figure 16.- Lateral stability characteristics of the model up to high angles of attack with vertical tail on and off. $i_t = 15^\circ$.

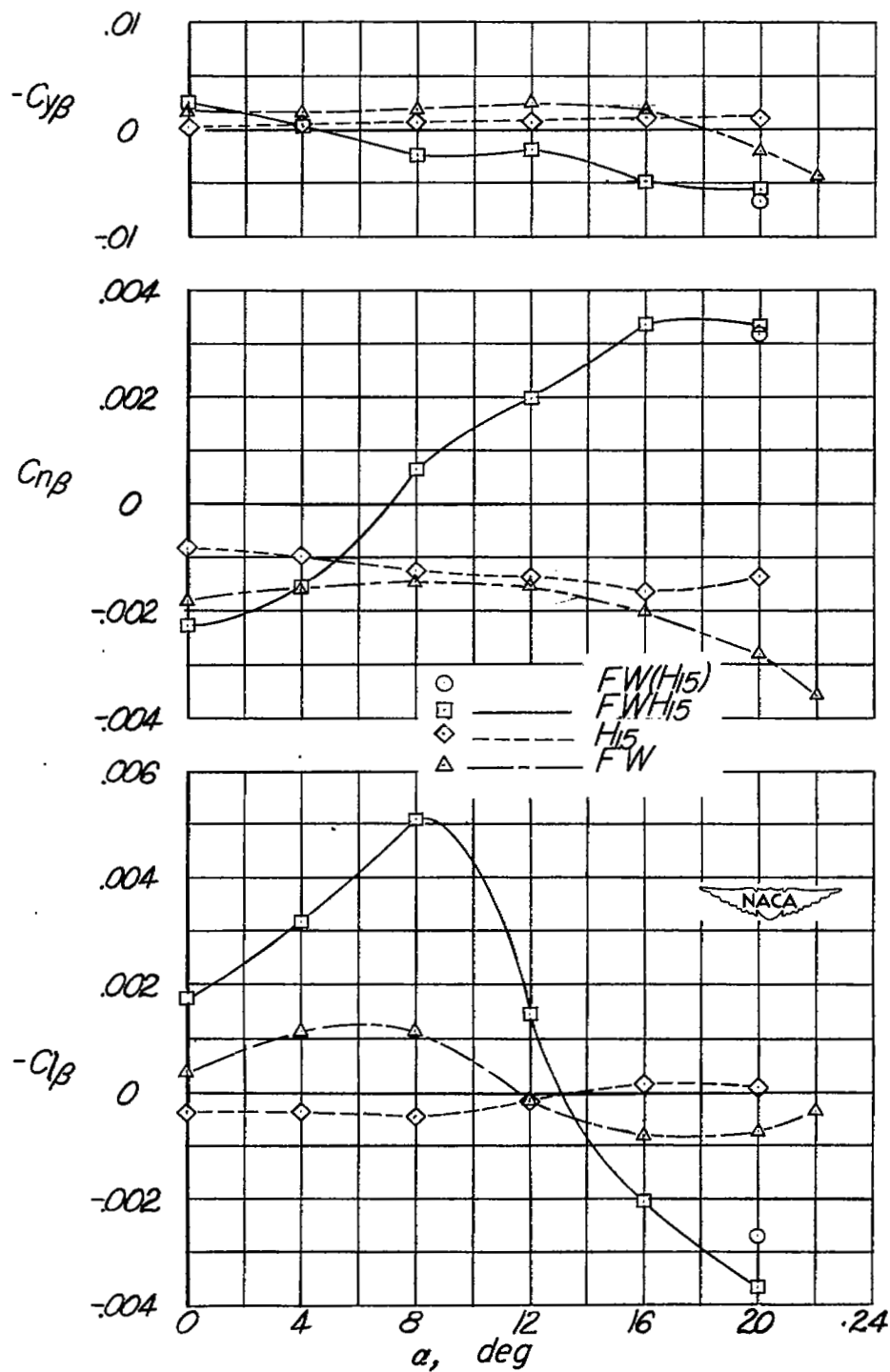


Figure 17.- Comparison of the lateral stability of the model with the horizontal control surface attached and unattached. Vertical tail off.

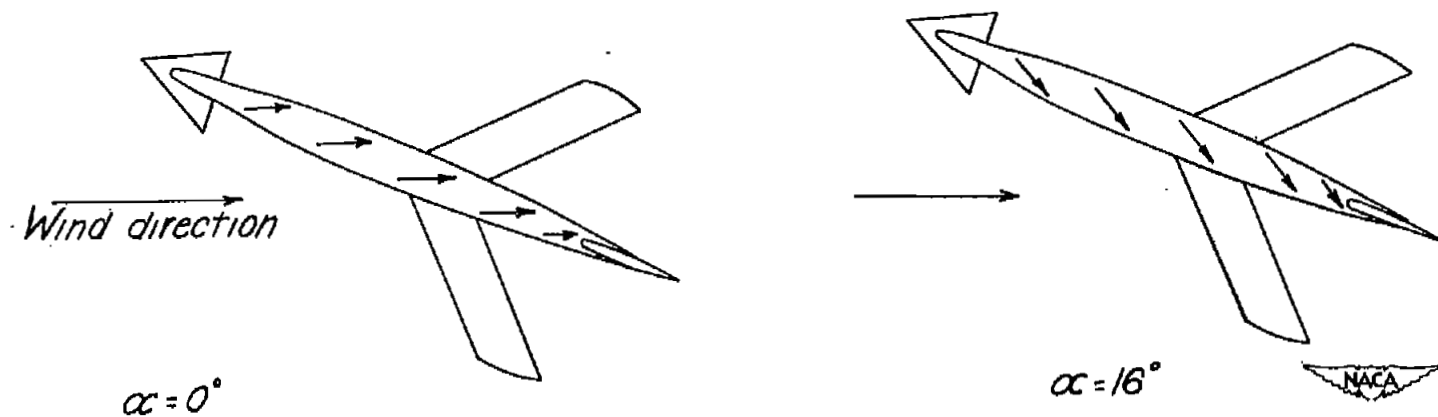


Figure 18.- Direction of air flow over the fuselage for small angles of yaw. $i_t = 15^\circ$.

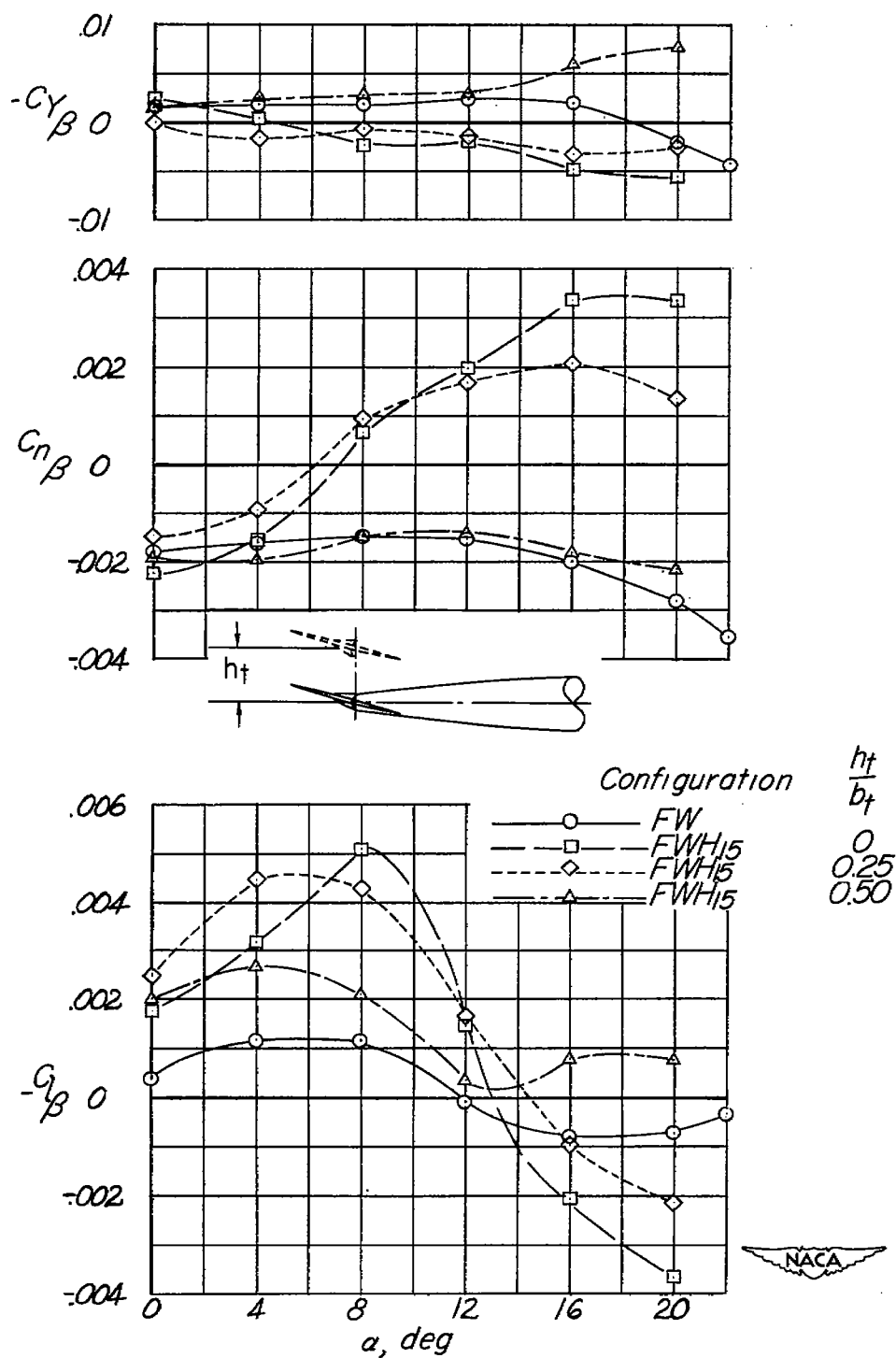


Figure 19.- The effect of vertical location of the horizontal control surface on the lateral stability characteristics of the model.

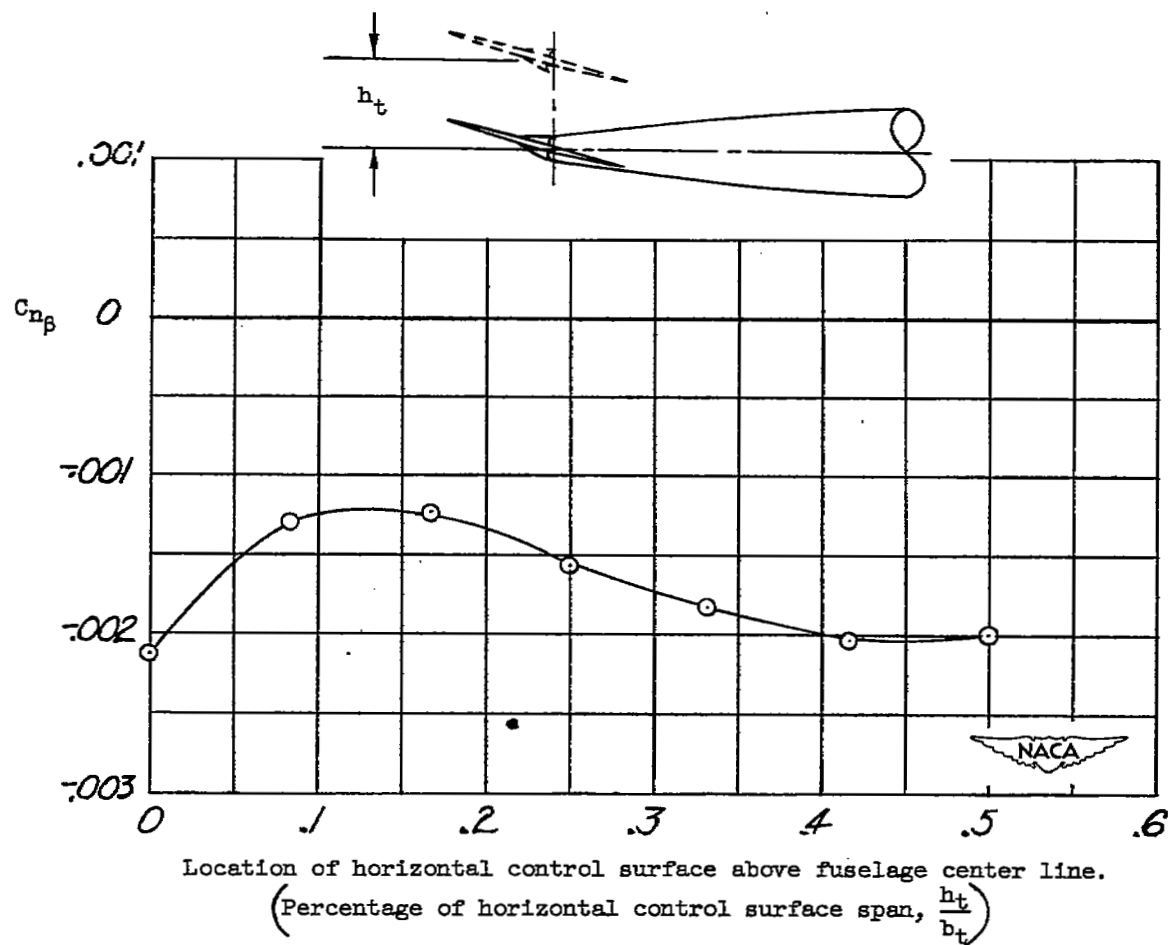


Figure 20.- The effect of vertical location of the horizontal control surface on the directional-stability parameter of the configuration of fuselage, wing, and horizontal control surface of the model.
 $i_t = 15^\circ$, $\alpha = 0^\circ$.

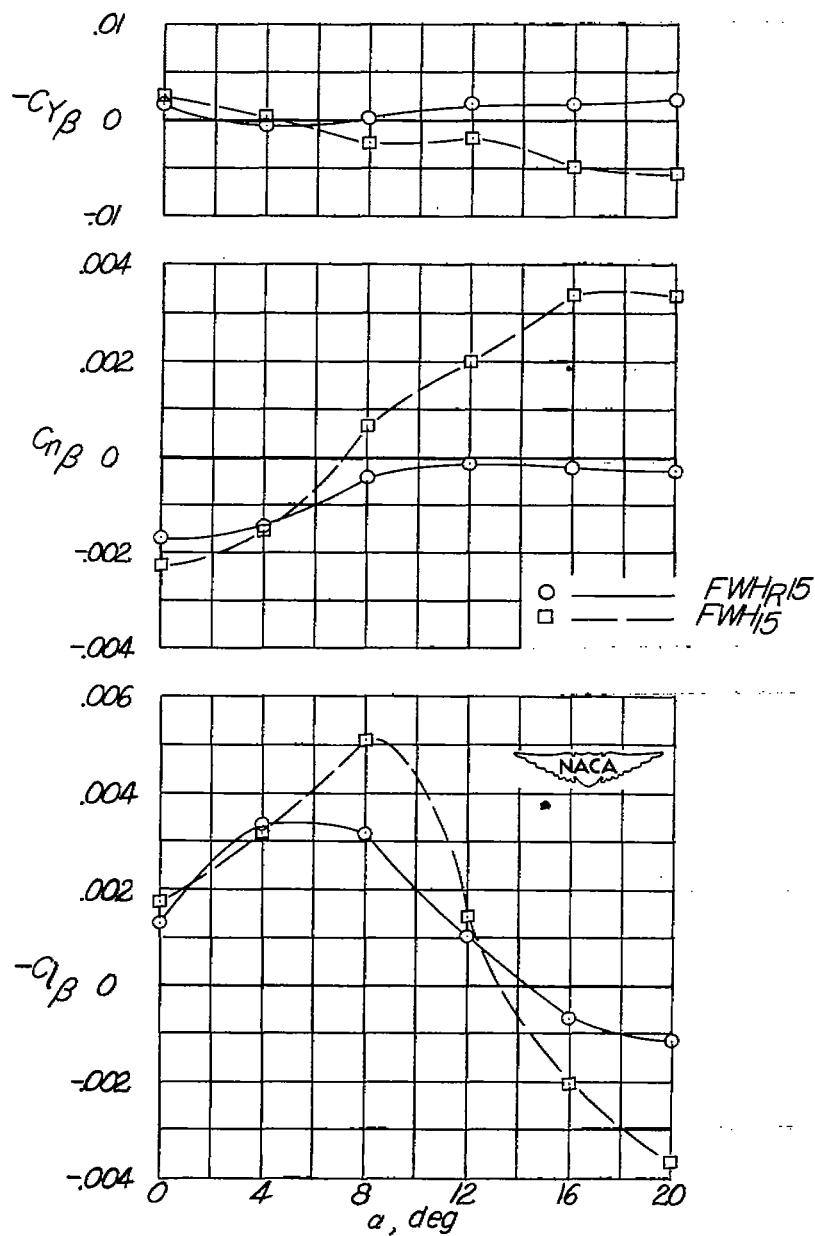


Figure 21.- Comparison of the lateral stability characteristics of rectangular and triangular horizontal-control-surface configurations of the model.

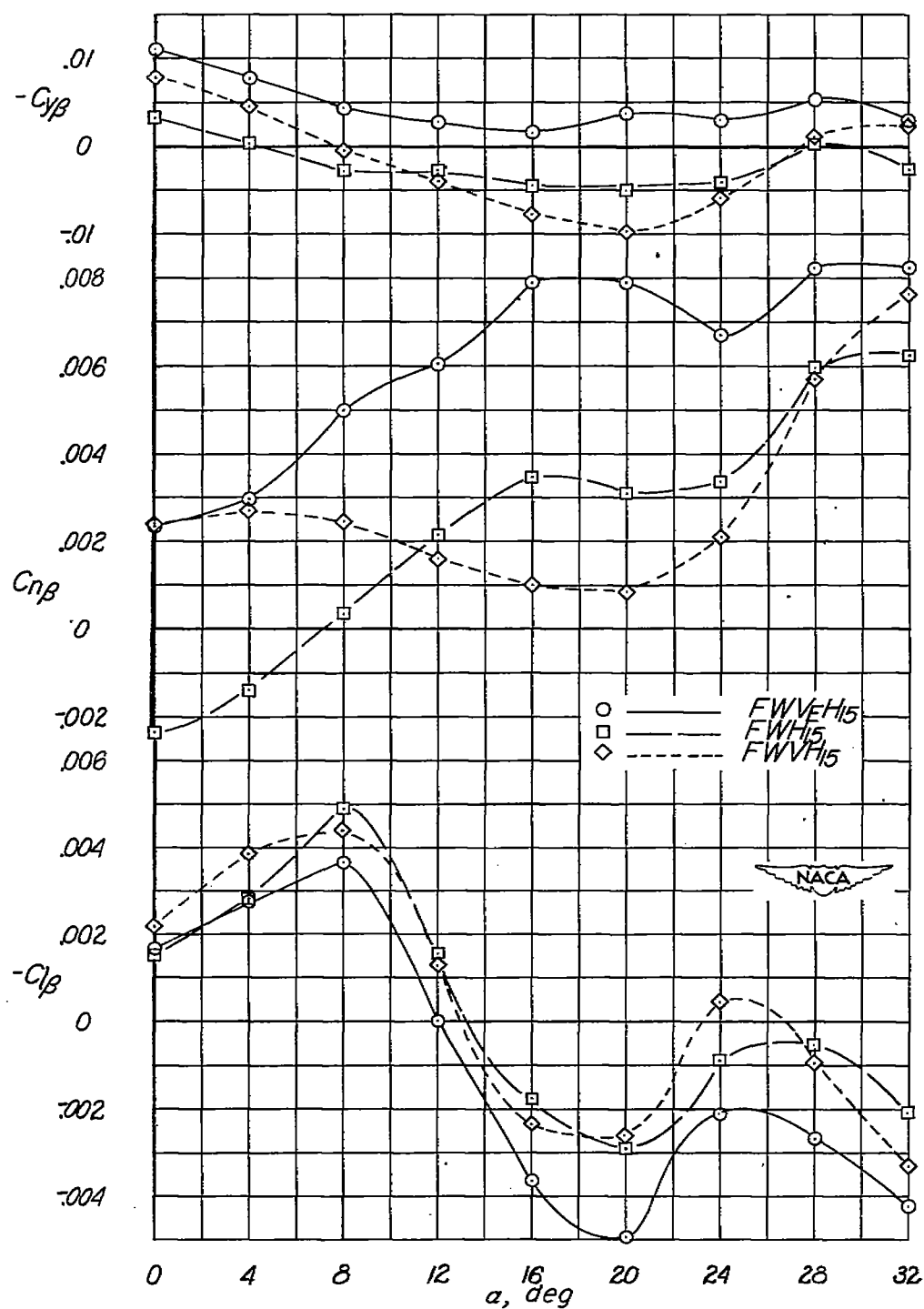


Figure 22.- Comparison of the lateral stability characteristics of single and twin vertical-tail configurations of the model.

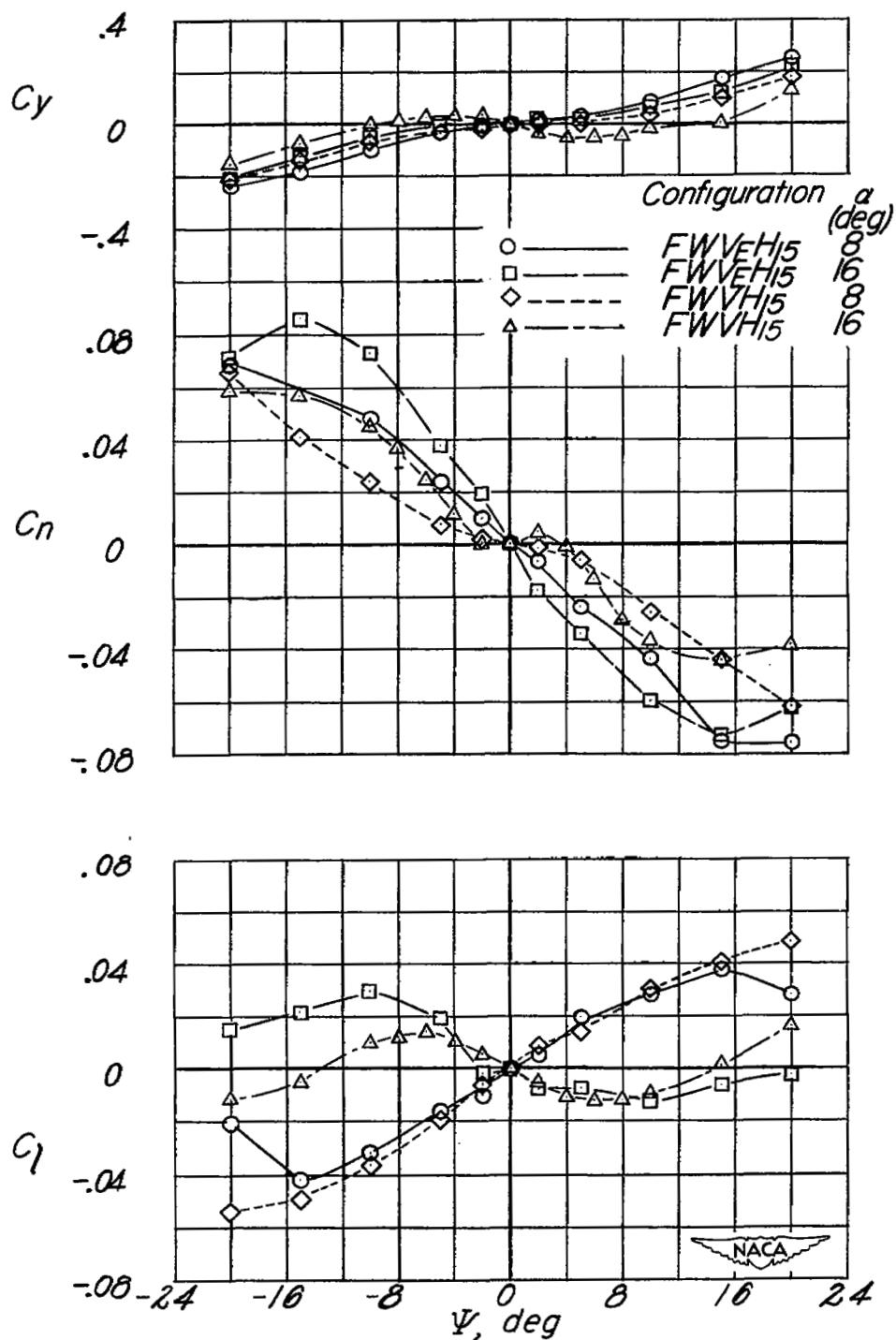


Figure 23.- Lateral characteristics of the model with single and twin vertical-tail configuration.

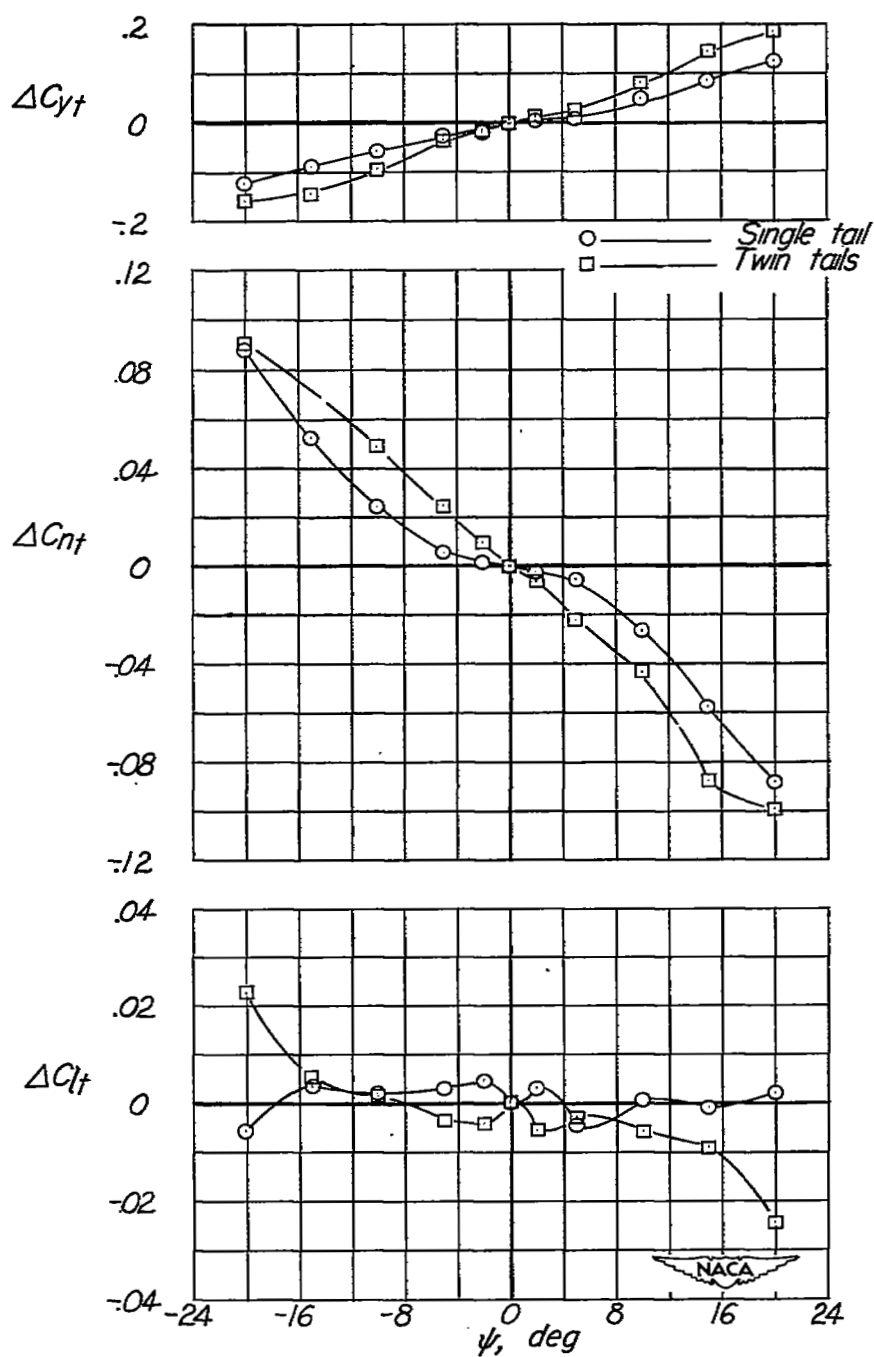
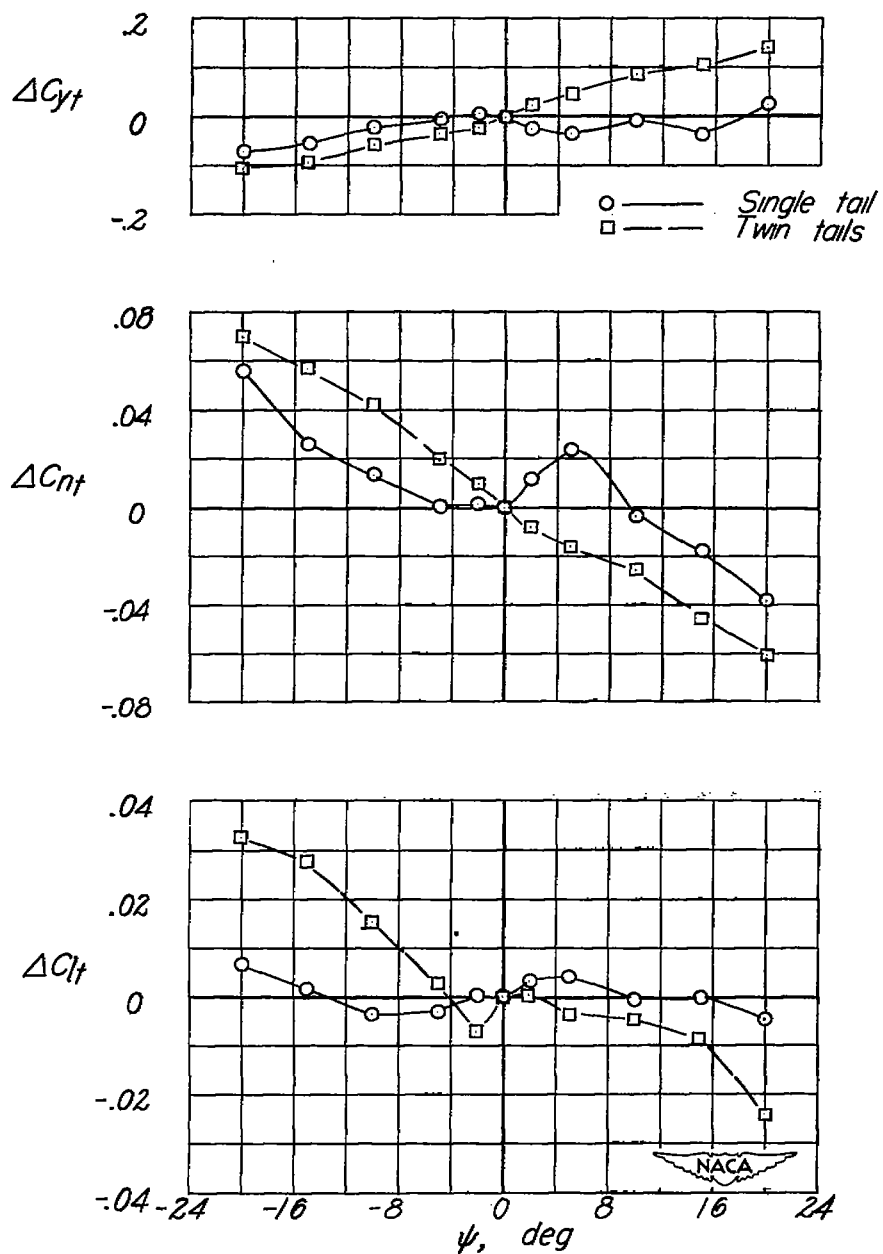
(a) $\alpha = .8^\circ$.

Figure 24.- Incremental lateral stability of single and twin vertical-tail configurations of the model.



(b) $\alpha = 16^\circ$.

Figure 24.- Concluded.

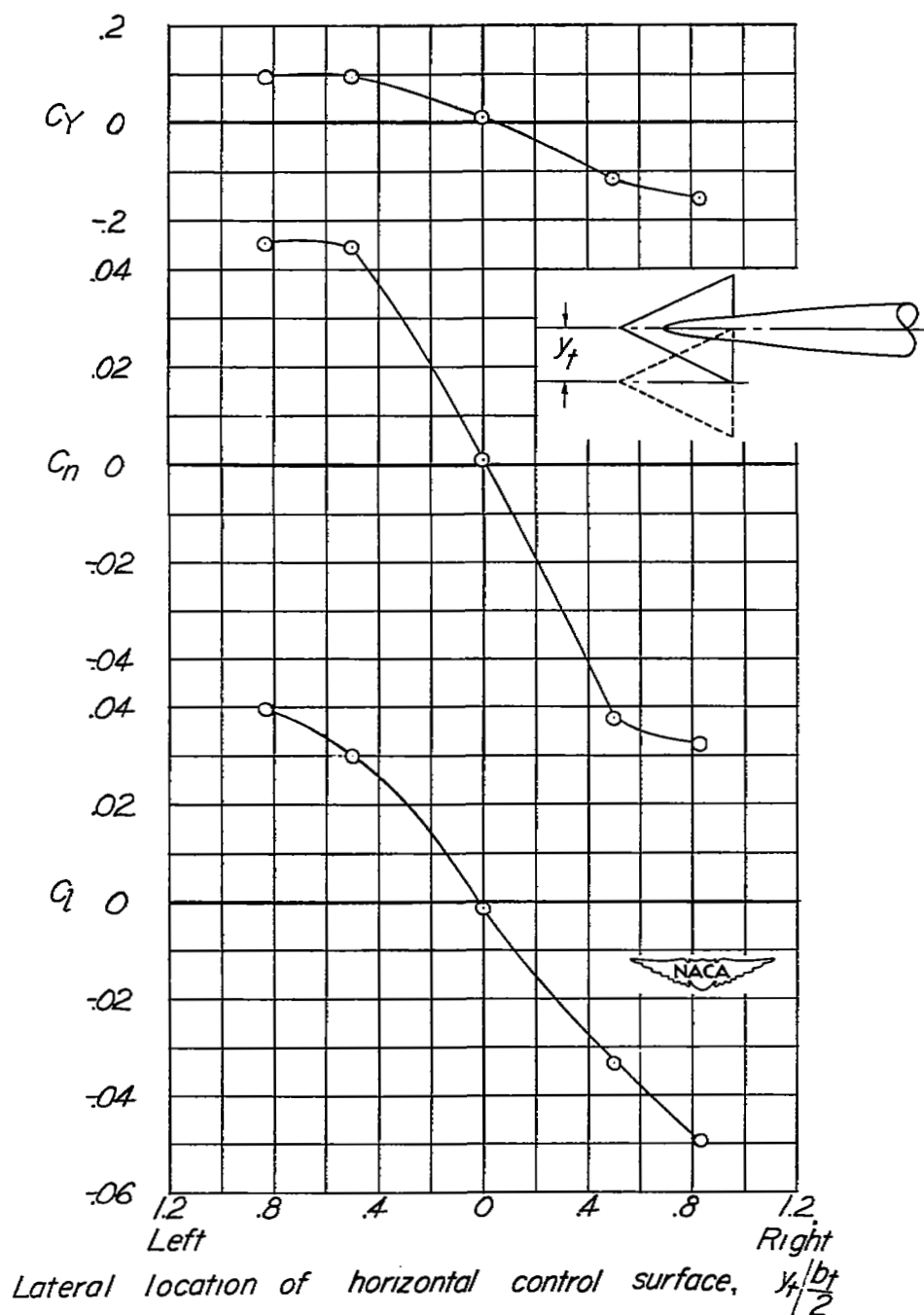


Figure 25.- The effect of lateral location of the horizontal control surface on the lateral characteristics of the configuration of fuselage and wing horizontal control surface of the model. $i_t = 15^\circ$, $\alpha = 15^\circ$.

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